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Photochemical Air Pollutant Effects on Mixed Conifer Ecosystems

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PHOTOCHEMICAL AIR POLLUTANT
EFFECTS ON MIXED CONIFER ECOSYSTEMS

A Progress Report

by

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In 1972, a multi-disciplinary team of ecologists assembled to monitor and analyze some of the ecological consequences of photochemical oxidant air pollutants in California Mixed Conifer Forest ecosystems of the San Bernardino Mountains east of Los Angeles. The purposes included gathering documentary evidence on the impact on these forests, designing a computerized data management system to process the data, and constructing computer simulation models to project possible future consequences. Seven meteorological and air quality monitoring stations have been maintained, nineteen mountain study plots have been examined for air pollution injury to vegetation, and a variety of additional plots have been identified for studying soil conditions, tree growth and death, tree diseases, bark beetle interactions, needle litter build-up beneath trees, decay of dead wood in the forest, microarthropods in the litter, and microbial breakdown of pine needles. Additional work examines conifer tree seed production in relation to small mammal populations and oxidant levels, as well as long-term changes occurring in the kinds of trees present.

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ABSTRACT

In 1972, a multi-disciplinary team of ecologists assembled to monitor and analyze some of the ecological consequences of photochemical oxidant air pollutants in California Mixed Conifer Forest ecosystems of the San Bernardino Mountains east of Los Angeles. The purposes included gathering documentary evidence on the impact on these forests, designing a computerized data management system to process the data, and constructing computer simulation models to project possible future consequences. Seven meteorological and air quality monitoring stations have been maintained, nineteen mountain study plots have been examined for air pollution injury to vegetation, and a variety of additional plots have been identified for studying soil conditions, tree growth and death, tree diseases, bark beetle interactions, needle litter build-up beneath trees, decay of dead wood in the forest, microarthropods in the litter, and microbial breakdown of pine needles. Additional work examines conifer tree seed production in relation to small mammal populations and oxidant levels, as well as long-term changes occurring in the kinds of trees present.

From the late 1960's, through the present 1974, documentary evidence shows that both concentration and dose of oxidant air pollutants are continuing to increase at locations in the San Bernardino Mountains and extremely exceed Federal Air Quality Standards. This condition can influence infection and colonization by Fomes annosus, one of a set of processes contributing to tree mortality. The rate of bark beetle attack was lower on individual oxidant-injured ponderosa pines, but

fewer beetles were required to kill oxidant-injured trees. These forests have no noticeable shortage of necessary plant nutrients in the soils, but a drought stress to vegetation, beginning in July and August, is preceded by an active growth period beginning in May. Air pollution injury to vegetation can be expected to increase during this accelerated growth period. Between 1973 and 1974, visible air pollution injury to pine trees increased in 37 percent of the study plots, while the annual death rate per plot was ten times greater in areas showing at least slight visible injury, compared to plots having very slight or no visible injury.

Merchantable volume growth of ponderosa pine trees, 30 years of age, is reduced by 83 percent in zones of highest ozone concentration. Pine needles fall from the trees and accumulate on the ground at a faster rate as visible oxidant injury increases to a moderate level. With increasingly severe injury, needle litter production falls off, since fewer and smaller needles are produced under these conditions. A decrease in the abundance and diversity of small mammal populations is found on sites subjected to greater oxidant concentrations.

This report was submitted to describe the progress of Contract Number 68-03-0273, by the Statewide Air Pollution Research Center, University of California, Riverside, sponsored by the Environmental Protection Agency. Work has not yet reached completion.

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51-62	Joe R. McBride Dept. Forestry & Conserv. University of California Berkeley, California	Vegetation

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199-210	Robert F. Luck Dept. of Entomology University of California Riverside, California	Cone and Seed Produc- tion for Dominant Conifer Tree Reproduction
210-221	Marshall White, and K. McDonald Dept. of Forestry & Conserv. University of California Berkeley, California	Distribution and Role of Wildlife Popula- tions Under Oxidant Pollutant Stress

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221-225	Joe R. McBride	Long-term Change in Forest Composition: Succession of the Vegetation

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SECTION I

INTRODUCTION

Since 1972, a multidisciplinary study has been underway to determine the impact of oxidant air pollutants on the mixed conifer forest ecosystem in general, and on two dominant tree species (ponderosa, Pinus ponderosa Laws, and Jeffrey pine, P. jeffreyi Grev. and Balf.), in particular. The ecosystem studied was in the San Bernardino National Forest (SBNF) in southern California. The study is supported through a contract with the Environmental Protection Agency. This effort involves researchers on the Riverside and Berkeley campuses of the University of California and from the U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station. The San Bernardino National Forest is administered through the local U.S. Forest Service, Supervisor's Office in San Bernardino, California. A large measure of progress in the study has resulted from the helpful cooperation of District level Forest Service personnel.

The SBNF includes approximately 64,750 ha (160,000 acres) of mixed conifer and hardwood forest extending from Cajon pass northwest of San Bernardino, and eastward to the San Gorgonio pass near Palm Springs. The SBNF consistently has been the most frequently visited National Forest in the United States with 6.0 million visitors in 1973. The areas included in the study range from 1368 to 2279 m (4,500 to 7,500 feet) elevation.

The SBNF lies at the north and east boundaries of the South Coast Air Basin (SCAB). Extensive urban and industrial development in the

SCAB since 1940 has caused a rapid increase in oxidant air pollutants. Combustion of petroleum base fuels for transportation, generation of power and industrial operations release massive amounts of nitrogen oxides and reactive hydrocarbons to the atmosphere.

Photochemical reactions involving these compounds generate ozone (O_3) and peroxyacetyl nitrates (PANs) and intermediate compounds. Ozone and PANs are both strong phytotoxicants and the PANs are strong lachrymators. Ozone concentrations frequently exceed $600 \mu\text{g}/\text{m}^3$ (30 parts per hundred million (pphm)) in the SCAB and occasionally reach levels of $1200 \mu\text{g}/\text{m}^3$ (60 pphm); it accounts for approximately 85% of the total oxidant measured in polluted atmospheres. PANs seldom exceed 30 parts per billion (ppb), but they are many times more phytotoxic than ozone.

The strong thermal inversions which characteristically form over the basin, and the daytime, eastward drift of marine air under the inversion provides an ideal delivery system to transport pollutants from the basin to the SBNF. Typically the overall dosage of oxidant pollutants in exposed parts of the forest exceeds that received by areas in the SCAB.

Unusual injury symptoms, principally to ponderosa pine, i.e., a characteristic type of needle mottle, defoliation, short needles and reduced twig growth, were first recognized in the SBNF in the early 1950's. These symptoms were subsequently determined to be caused by exposure to oxidant air pollutants. While the injury was severe on many ponderosa pines in the area, early researchers observed that some companion species were much more tolerant and that individuals in the ponderosa species were more tolerant than others. Pollutant

injured trees were observed to be more susceptible to bark beetle attack. Consequently pollutant injury and the increased activity of bark beetles have led to a forest management practice called sanitation salvage logging, which requires an increasing amount of harvest of oxidant-injured ponderosa and Jeffrey pines considered to have a high risk of being attacked by bark beetles.

Loss of timber volume can be considered significant but the greatest economic and esthetic impact is presently on the recreational and watershed values. Direct effects on major tree species can be observed, and short-term economic loss may be estimated; but, the long-term effects of oxidant injury and present management practices on the total ecosystem, which will irreversibly alter the total character of the forest, are only dimly perceived.

The present study is intended to identify and, where possible, measure the direct and indirect effect of the oxidant pollutants on interdependent populations in the forest. Results from investigations into oxidant pollutant interaction with vegetation successional trends and with dependent populations of consumers, decomposers, and with the management practices imposed on these populations will be used to construct models useful in predicting future events.

In Figure 1, the detailed locations of various study sites (large rectangles) in the SBNF are shown on a background of the overstory vegetation types defined by U.S. Forest Service timber inventory standards. The most important sites are the 19 major vegetation plots which are located along a decreasing gradient of total oxidant dose in a west to east direction. One of the most important kinds of data gathered is

the oxidant injury score of trees, herbs and shrubs.

Air monitoring stations, all measuring total oxidants, are similarly distributed. The stations located at Camp Paivika (CP), Sky Forest (SF), and Barton Flats (BF) telemeter ozone concentrations, wind, temperature, relative humidity, and net radiation to a master station at the U.S. Forest Service Fire Laboratory in Riverside. The stations are normally polled once hourly throughout the May-October period. The station at Sky Forest also measures peroxyacetyl nitrate (PAN), nitrogen dioxide, sulfur dioxide, and particulates including lead. Wind speed and direction are available at several Forest Service stations once daily. These are indicated by an elbow-shaped symbol.

Other special experimental plots have been established to describe the characteristics of surviving or new vegetation in areas which represent a variety of elapsed times after wildfires. These successional stages are usually comprised of fewer species than the mature or climax conifer forest and may have less resiliency to oxidant stress.

The population dynamics of pine bark beetles are studied by locating infested ponderosa or Jeffrey pines as soon as possible after initial attack. This kind of sample plot may consist of only one tree at a given site. These plot locations for 1973 and 1974 are indicated by open circles enclosing numerals. The numeral describes the generation of the insect for each year. The dark squares represent three plots ranging up to 90 X 120 m in size which are cooperatively studied by the vegetation and bark beetle subprojects. An attempt is being made to relate the degree of oxidant injury to ponderosa pine with the probability of bark beetle attack.

Plots to study rate of natural spread of F. annosus root disease from dead stump(s) representing the point of initial infection at a site to nearby trees are represented by a dark circle. The locations of semipermanent F. annosus root inoculation studies, e.g. near Snow Valley are not shown.

Other research projects are located nearby or within each of a selected number of the major vegetation plots. Some examples include:

1. Collection and measurement of winter precipitation.
2. All year measurements of soil temperature and soil moisture depletion and recharge cycles.
3. Collection and measurement of litter fall; studies of litter decomposition including decomposers (fungi and microarthropods).
4. Measurement of cone and seed production.
5. Trapping of small mammals.
6. Annual inspection to detect the incidence of other insect and disease pests.
7. Analysis of stand age and structure.

Project personnel work out of a common lodging place located at Running Springs which can be identified in Figure 1 as a triangular symbol for an air monitoring station just east of the Camp O-ongo (C00) vegetation plot.

SECTION II

CONCLUSIONS

REGARDING THE PROCESS OF DERIVING RECOMMENDATIONS

Since this is a systems project, and since a systems ecologist was only recently added to the project in early 1975, it is inappropriate, and would be misleading, to give air quality management and forest resource management recommendations unless and until they can be based upon systems analysis and computer simulation of the systems. To do otherwise, would lead to fragmented recommendations which would not evaluate the various ecological impacts caused throughout the system from the possible implementation of such recommendations.

REGARDING THE FOREST ECOSYSTEMS

Trends in the Oxidant Air Pollution Climate

An inescapable consequence of the particular topography and meteorology of the South Coast Air Basin, including the San Gabriel and San Bernardino mountains, is the deep and frequent penetration of oxidant polluted air into the montane conifer forests east and northeast of Los Angeles. Year to year changes in the frequency of high air pollution episodes in this air basin are closely correlated with one particular synoptic pattern, namely, a persistent upper level (500 mb) high pressure system over the southwest.

Comparisons of total oxidant dose, during the June through

September period in the Rim Forest/Sky Forest area of the San Bernardino mountains since 1968, suggest that the annual doses in this period have remained high and did definitely increase in 1974.

Another comparison of episodes when total oxidant concentrations have exceeded $329 \mu\text{g}/\text{m}^3$ (0.20 ppm), during July through September from 1963 to 1974 in downtown San Bernardino, and at Rim Forest/Sky Forest in the mountains from 1968 to 1974, shows an alarming increase at both stations even when 3-year moving averages are used to help remove some of the variability due to meteorology. The worst year on record at both stations was 1974.

A network of seven air monitoring stations, located along a 25-mile long west to east transect (between the elevations of 1617 m in the west and 2067 m in the east) in the San Bernardino mountains in 1974, have shown that total oxidant dose is 2/3 lower on the eastern end. The western portion generally receives more nighttime hours of high total oxidant concentrations.

Impacts on Vegetation Injury, Mortality, and Litter Accumulation

Oxidant Effects on Forest Tree Pathogens ---

Preliminary observations show that oxidant air pollutants may reduce the resistance of conifer tree roots to infection by the disease fungus Fomes annosus. If this conclusion is substantiated by data from work not yet completed, increased destruction by F. annosus in the future is quite possible. Another important consideration is that the fungus often causes greater damage in forests which are cut periodically. This situation occurs throughout the San Bernardino

Mountains due to necessary removal of air pollution and disease/insect killed trees. Therefore, F. annosus, currently an important and widespread pathogen in the area, may become even more damaging in the future.

Oxidant Effects on Bark Beetle Infestations ---

The western pine beetle attacks and kills trees over a considerable period of time during the course of a year, but for purposes of sampling, two peak periods of attack during a year are considered, and these are treated as generations. There is an early summer generation and a late summer generation which is the overwintering generation.

The only information summarized and analyzed in a cursory manner is the egg data. From a look at this information, it appears that the populations of western pine beetle in the San Bernardino Mountains of southern California are unique when compared with populations at Blodgett Forest in northern California, an area not attacked to any large extent by photochemical air pollutants.

Attack rates of beetles in the San Bernardino area varied by generation and by oxidant air pollutant-tree injury class. Attack rates in the first generation were higher than those in the second generation in both 1973 and 1974. Attack rates were generally higher on those trees with the least amount of oxidant air pollutant injury. Attack rates in the first generation of 1973 were much higher in the SBNF than those recorded at any time at Blodgett Forest.

The number of eggs deposited per centimeter of gallery length was usually lower in the first generation than in the second generation. This is similar to the pattern of egg deposition at Blodgett Forest.

However, the mean number of eggs per centimeter of gallery in pollutant injured trees in the SBNF was much lower than the rates recorded at Blodgett Forest.

The mean percentage of hatched eggs, which can be used as an indicator of egg mortality, was similar in the first generation in the SBNF and unpolluted Blodgett. In the SBNF, survivorship was much greater in the first generation than in the second generation, a pattern which did not occur at Blodgett. Also, survivorship was generally higher in oxidant-injured trees.

These data have not been analyzed statistically but the trends indicate that further summarization and analysis of all data sets will yield information to show that the interaction between oxidant-injured stands of trees and western pine beetle populations is indeed unique.

From a cursory look at one data type, it can be concluded that photochemical air pollutants affecting ponderosa pine can indirectly depress attack rates of the western pine beetle, have a variable effect on, but possibly depress, the mean number of eggs per centimeter of gallery length, and increase egg survivorship rates.

The California flatheaded borer was found to be an important competitor with the Jeffrey pine beetle.

Soil Climate and Drought Stress on Vegetation ---

The soil moisture regime has been documented for 23 sites beginning in the summer of 1973 to the present and measurements are continuing. Soil moisture depletion is most rapid during June, and the upper 1.5 m of soil is depleted of soil moisture available for plants by

about mid-July. However, some moisture at depths up to 2.7 m (9 ft) is used by plants into August. The period of dynamic growth appears to be from May to August, and it appears that air pollutant injury to plants coincides with this period. The total storage capacity of soil moisture available to pine trees in this system is generally considerably higher than the 15 cm often assumed in water balance studies.

Soil temperature regimes at 23 sites have been recorded since mid-summer 1973. Preliminary analysis of the data suggest that mean annual soil temperatures range from about 4.5 C to 11.5 C in the general study area, with even higher soil temperatures on south facing aspects. Warm and cold sites, dependent upon aspect and slope, can be found throughout the range of air pollutant concentration.

Precipitation was collected both outside and under the crown of a number of trees at Camp O-Ongo plot affected by air pollutants. It was found that significantly more precipitation reached the ground surface under the trees, than outside; this effect is assumed to be due to the wind which causes the rain to fall at an angle rather than vertically.

Soil Nutrients for Vegetation Growth ---

The concentration of cations in the precipitation is only 1/5 of the concentration in the crown-drip near the trunk. The relationship of the chemical composition of the crown-drip to air pollutant impact on the trees is obscured by the variability due to differences in path of water moving from needles to twigs to large limbs before falling to the ground surface.

Chemical analyses show that the soils generally contain adequate mineral soil nutrients, especially calcium, which is often very low in more humid forested soils. Also, the soils contain reasonably high amounts of organic matter, and, with few exceptions, contain adequate nitrogen for forest growth.

Vegetation Injury and Death ---

The relative doses of total oxidant received by ponderosa or Jeffrey pines in 19 major vegetation plots along the oxidant monitoring transect can be estimated from 1974 data. Going generally from west to east, three plots were described as having severe injury, ten were moderate, one slight, two very slight, and three had no visible symptoms. The average amount of injury, based on scores of individual trees, increased in seven of the 19 plots from 1973 to 1974.

During this period, the mortality of ponderosa and Jeffrey pines ranged from 0.0 to 8.0 percent and averaged 2.9 percent in plots categorized as slight, moderate and severe injury. Mortality was less than 0.3 of one percent in the remaining plots described as very slight and no visible injury.

At the end of August, 1974, observations of injury to black oaks, where present in the 19 major vegetation plots, indicated a distinct gradient of decreasing leaf injury in the first 2/3 of the west to east transect.

So far, oxidant mediated mortality has not been observed in tree species other than ponderosa and Jeffrey pines.

It is very important to understand that the present level of

injury to woody vegetation is the result of annual doses of oxidant much lower than those recorded in 1974. Since the 1974 oxidant dose was the highest on record it should not be used alone to estimate vegetation dose responses.

Oxidant Effect on Conifer Tree Growth ---

Quantification of the diminished needle leaf production and small stem ~~tissue~~ production due to chronic oxidant exposure in sapling size ponderosa pines suggests: (1) only a few trees may survive and grow into larger size classes to replace dying overstory trees; (2) the rate of growth of surviving trees will be slower, thus altering their competitive ability with respect to competitors in both the understory and overstory; (3) less materials and energy will be transferred to the consumer and decomposer levels in the ecosystem; and (4) sapling data from this study will enable estimates of biomass decreases in larger trees which cannot be enclosed in greenhouse structures.

Oxidant air pollution in the forests of the San Bernardino Mountains reduce the average annual diameter growth of ponderosa pine by approximately 40% in trees under 30 years of age. Merchantable volume growth of trees 30 years of age is reduced by 83% in the zones of highest ozone dose. This reduction in growth, along with air pollutant caused tree mortality, is of significance to the continued production of timber in the San Bernardino Mountains.

Pine Needle Fall and the Forest Floor ---

Pine needle fall, collected on screens under trees in the fall of 1974, especially in the Lake Arrowhead regions, shows little accumula-

tion under trees only slightly injured by oxidant air pollutants, a marked increase under trees which were moderately affected, and a sharp decline where trees were strongly injured. The latter case reflects the scarcity and small size of needles which remain on the severely injured trees.

The mass and length of the individual needle fascicles decreases linearly with increasing air pollutant injury to the tree.

The thickness and mass of the forest floor (pine needle litter) is shown to be greater at lower elevations, i.e. the Lake Arrowhead Region and at Camp Angelus in the lower Santa Ana Canyon, than at higher elevations. However, it was found that the thickness of the litter layer was much more markedly reduced where disturbed by heavy recreation activity or even by selective logging.

After selective felling of beetle infested trees or repeated sanitation salvage logging, particularly in the ponderosa pine and ponderosa pine-white fir forest types, the accumulation of heavy fuels, e.g. slash, represents a serious wildfire risk which would result in hotter fires.

Impacts on Litter Decomposition

As oxidant injury to conifer trees increases, the population sizes of microarthropods acting as litter decomposers in the forest soil also decrease.

Renewal of Mixed Conifer Forest Ecosystems as Biological Resources ---

In 1974, a larger than average cone crop was produced. Trees of

dominant crown class were the greatest contributors: 73% of the trees which bore cones in 1973 were dominant, and 63% of the trees in 1974 were dominant. When compared to the 1973 crop, a greater percentage of the 1974 crop was born by trees belonging to crown classes other than dominant. Furthermore, those trees which bore cones in 1974 produced a larger number of cones per tree. A large number of factors are known to affect cone crop size; hence, data from a period of years are essential before the influence of some of these factors can be sorted out.

The diversity and abundance of small mammals varies among the major study plots. The data suggest relationships between oxidant dose, oxidant injury rating of vegetation, and the number of small mammals encountered.

The western gray squirrel, abundant throughout the forest ecosystem, feeds heavily on conifer seed by cutting green cones from the trees. An alteration of the balance between pine and oak trees or a change in the squirrel population due to oxidants, will affect the balance of the seed-squirrel relationship and have a significant influence on the forest, especially pine and oak regeneration. Most cones are cut prior to seed maturity. Such destruction of the potential reproduction of conifer trees may be acting together with oxidant injury to seriously reduce pine regeneration and thus hasten vegetation change.

REGARDING RAMIFICATIONS FOR SOCIETY

Decreased Timber Production

Some of the socio-economic consequences of the biological events observed must be suggested. First, the potential productivity of the forest for wood products must certainly decline. The merchantable overstory has already been removed in some areas, and the rate of growth of small timber into merchantable size classes is severely restrained in the moderate and severely oxidant-injured areas. At this point, there are no operational management practices known which can ameliorate the continued losses.

Degraded Recreational Experience

Second, the quality of the recreational experiences of residents and visitors will continue to decline. Published methods exist which permit conversion of recreational pursuits into monetary values. The San Bernardino National Forest continues to top the country's National Forests in visitor-days of use at 6,053.5 M in 1973. The monetary value of recreation enjoyed by visitors can range from \$4,237.5 M (\$0.70/person) to \$45,401.3 M (\$7.50/person) in 1971 dollars, based on 1973 visitor data. The difference is related to the type of recreational pursuit. Visitors will enjoy much less for their investment. The added stress to health by exposure to oxidant doses greater than in the basin has not been included. Many recreational pursuits require increased physical activity which only adds to the total stress.

Conflict with Wilderness Ethic

Third, one of the most important characteristics of wilderness: "where man has passed, let no sign of man remain", has been rendered meaningless in portions of the San Geronio Wilderness Area. Oxidant air pollution has brought this about in a unique manner.

REGARDING APPROPRIATENESS OF RESEARCH METHODS

The soils on the major study plots have been classified according to "Soil Taxonomy" (USDA - SCS 1973 preliminary text) and assigned soil series names where applicable. The soil classification is adequate for comparisons of the impact of a range of oxidant air pollutant on vegetation growing on essentially similar sets of soils.

Physical analyses of the soil show that most of the soils are relatively uniform and low in clay content throughout the soil above the contact with decomposed granite substrata. This simplifies the possible comparison of the effect of soils on the relative air pollutant injury to the vegetation. Two soil areas which have more clay in the subsoil have similar soil temperatures but widely differing intensity of air pollutant, so these two are suitable for comparison.

Studies were initiated on the mountain pine beetle and the Jeffrey pine beetle in 1974. In an effort to develop sampling methods for both these bark beetles, various sized samples were taken. These data have not been thoroughly analyzed, but it appears that paired 500 cm² samples will be suitable for each species.

The oxidant air monitoring network employed in 1974 provided a good measure of the decrease of oxidant dose with distance from the basin (SCAB); however, the complex effect of mountain terrain on surface air flow and pollutant dispersion will require that additional temporary pollutant and wind monitoring stations be maintained in selected configurations for short (1-2 weeks) periods.

The mathematical model of surface wind flow in mountainous terrain, where no monitoring stations were available, promises to be a feasible method for determining and describing, with sufficient resolution, terrain influence on channeling and blocking of pollution advection through forested areas.

SECTION III

RECOMMENDATIONS

RESEARCH PLANNING

Objectives of this research program fall in two general categories. The first objective is to gain a more clear understanding of the direct and indirect impact of photochemical oxidants on the interrelated biological components of a mixed conifer forest ecosystem. The second objective is to utilize these results in models designed to predict probable adjustments in the ecosystem to compensate for or encourage recovery from the pollutant impact. Ultimately it is anticipated that the models will be useful in relating the oxidant air pollutant impact on a forest ecosystem to some aspects of human welfare.

Information produced from this project will be largely in the form of scientific conclusions which will serve as a basis for future recommendations. Portions of the project in which the impact of oxidant pollutants can be identified and measured will be emphasized and enlarged but areas where little or no impact can be demonstrated should be deemphasized.

Design and development of a "Data Management System" by the Lawrence Livermore Laboratory is scheduled for completion by January 1977. Routine maintenance of the system after this data is essential; therefore, provisions must be made for a smooth transition.

It is suggested that groups of investigators meet on a regular, systematic basis for the purpose of designing and developing subsystems models, based on their field and laboratory research, and

oriented toward the overall problem of this program. Until such activity proceeds at least to the stage of quantifying the detailed relations expressed in the graphic flow chart versions of the models, but ideally to the stage of sensitivity analysis of the computer implementations of the systems models, an evaluation of the merit of some of the process studies recommended below cannot be given.

RESEARCH DEVELOPMENT

The following recommendations for critical research needs pertain directly to the systems study underway to describe the effects of oxidant air pollutants on a western mixed conifer forest ecosystem in the San Bernardino Mountains of southern California. The report of significant damage to similar forests in the southern Sierra Nevada of California emphasizes the need to understand the biological consequences of these tragic events.

Different ecosystem components change in magnitude on different time scales. Some change faster than others over a given time increment. Those components which change daily and are non-biological inputs to the ecological system are monitored for the purpose of driving the computer simulation models of the ecosystems. Data on these components are considered as validation data for the modeling effort.

Those components which change relatively slowly so that annual changes are virtually imperceptible are considered as site parameters. They are considered to be relatively constant and are used for making a model more applicable to a given site in the landscape and for determining the degree of spatial resolution needed in the model to gain

better realistic representation to the ecosystem in the landscape.

Those components which change relatively rapidly and together represent internal processes within the ecosystem are studied in order to quantify the functional relationships comprising the body of the model. These are process studies which should be accomplished in finite periods of time.

It is recommended that the evaluation of possible changes in process studies, either expansion, contraction, or continuation in contrast to the first two options, within this research program be classified according to the following levels of present understanding.

- Exploratory: (1) We don't know if a potential component actually exists on the study plots;
- (2) We don't know if a direct relationship exists between two existing components;
- Confirmatory: (3) We know potential components actually do exist on the study plots, as does a direct relationship between them, but we don't know how much of a change in one component is transferred to the others.

Environmental Monitoring for Driving System Models

A need is evident for models to diagnose and predict wind, air temperature, and humidity for remote regions where monitoring stations cannot be maintained. This information is necessary for driving dose-injury response models for forest vegetation.

Soil moisture and soil temperature readings need to be continued

in order to provide sufficient data to predict the long term soil moisture regimes from weather records and evaluate the timing of soil water availability with respect to oxidant air pollutant stress.

Site Parameter Determination

The topics of soil morphology and classification have been studied in sufficient detail.

Only a few more soils will need to be analysed for chemical and physical properties for plot parameterization. However, further analyses will be needed of surface soils directly related to individual trees variously affected by air pollutants.

Process Studies Determining Rates of Change of Ecosystem Components

Primary Productivity ---

One of the most important research goals is to understand the relationships of meteorological variables and related variables like soil moisture availability as they influence the oxidant dose - vegetation (injury) interaction. Additional data needed are programmed for collection during the next two calendar years but the definition of a dose-injury submodel should begin immediately. Additional emphasis must be placed on correlating other objective measurements of tree health with the present classifications derived from visible symptoms.

As a specific portion of dose-injury determinations, studies are needed relating soil moisture tension, xylem water potential and stomatal behavior to oxidant susceptibility of pines.

Consumer Control of Primary Productivity in the Ecosystem ---

Studies on the effects of air pollutants on the epidemiology of Fomes annosus need to be continued. Such work includes completed analyses of tree and stump susceptibility, continued establishment and monitoring of infection centers, and effects of pollutants on decay rates, growth, production and germination of reproductive spores, and genetic adaptability of the pathogen. Related studies including pollution effects on the pathogen's competitive abilities, and changes in pathogenicity and virulence should be conducted to give an adequate overall view of F. annosus - air pollution interactions.

Air pollution effects on the epidemiology of other important forest diseases, such as dwarf mistletoe and Elytroderma deformans needle cast, should be investigated. Further work on disease surveys should help to set priorities on these future studies.

Additional studies of damping-off fungi are needed to help clarify the effects of photochemical air pollutants on the composition, occurrence and density of these disease-causing organisms and their effect on regeneration and successional trends in the forest. These studies should include field and laboratory experiments concerning the types of damping-off fungi present, their population levels (endemic and those necessary for disease) and fluctuations, their relative position in the forest floor, their impact on seed germination and seedling establishment, and the effects of photochemical air pollutants on the fungi.

The initial phases of the study of the role of tree-killing beetles on Jeffrey and particularly ponderosa pines have shown some

interesting trends as to the influence of oxidant air pollutants on forest communities in southern California. There is no question that these beetles play a key role in causing mortality in the stands being studied. A preliminary look at portions of the data summarized to date indicates that the interaction between beetles and trees under these circumstances is unique, and the rate of tree killing will, in turn, influence the other biotic and physical processes under study in the overall investigation.

It is recommended that sampling of the western pine beetle on ponderosa pine be continued with greater emphasis on obtaining equal numbers of infested trees of each oxidant injury category in each generation. Further efforts must be made on those data already captured in terms of summarization and analysis. Because of the functional sampling methods available, the western pine beetle is the best insect indicator available for the influence of photochemical air pollutants.

Studies of the mountain pine beetle and the Jeffrey pine beetle will of necessity be of lower priority, but some small scale rearing studies should be continued.

Studies on the influence of the California flathead borer must be initiated, as this insect appears to be far more important in the system than previously thought, particularly on Jeffrey pine. Complementary surveys by the Forest Service should be encouraged; they will supply additional information and permit increased understanding of the influence of photochemical air pollutants on beetle-tree interactions.

Litter Accumulation ---

Thickness measurements of the forest floor (needle litter layer)

need to be extended to include all major plots, and to a study of individual trees.

Crown drip studies need to be extended to other plots for several years, as the problem of vandalism of the collector cans requires a large number of trials to obtain meaningful results.

Analysis of the nutrient status of needles falling from the trees is continuing and should be continued for at least one more year in order to determine the effect of air pollutants on the needles and consequently on the forest floor.

Consumer Control of Decomposition ---

Further detailed studies on the roles of, and the interactions between soil and microarthropods and soil microbes are needed to evaluate the effects of oxidants on needle quality and quantity and gross decomposition rates.

Fumigation experiments should be carried out to determine the effects of oxone on commonly occurring mite/fungus associations in the detrital decomposer food chains.

Evaluation of the effects of air pollutants on activity of litter decay fungi and on the resistance of woody litter to decay should be continued in order to determine whether oxidant air pollutants will change the rate of decomposition of fallen branches and tree trunks. Such a change could affect the availability of mineral nutrients necessary for stand regeneration.

Analysis of integrated needle litter decomposition will be completed in 2 years for sample materials now in the field. Further

similar experiments involving the same, and perhaps additional trees will be necessary in order to substantiate the results of this first experiment. Additional studies are planned to begin in the fall of 1975.

Fumigation experiments must be carried out in which sterilized needles from trees involved in the integrated field needle decomposition study are inoculated with individual isolates of predominate organisms and subjected to fumigated or filtered air and incubated at room temperature of 12 C.

At least two more years of data will be required to form an accurate picture of the succession of microorganisms involved in foliage decomposition. This will involve sampling of needles on trees prior to litter fall as well as sampling needles separated annually by nylon mesh squares on the forest floor.

In order to evaluate trends of fungal populations, fumigation experiments to determine growth rate, spore production, spore viability percentage, must be carried out with isolates of common decomposer fungi from selected sites.

Long-Term Vegetational Succession Under Oxidant Stress

It is absolutely essential that the previously described studies be synthesized in order to develop a plant succession model; the purpose of the model is to predict the species composition and structure of forest stands subjected to different doses of oxidant pollutants.

SECTION IV

CLIMATE AND PRESENT STRUCTURE OF THE MIXED CONIFER FOREST ECOSYSTEMS

CLIMATE

Temporal and Spatial Trends of Temperature and Precipitation

The climate of the San Bernardino Mountains is distinguished by its Mediterranean character with maximum precipitation during the cold months of November to April and minimum during the months of June, July and August. The relationship between mean monthly precipitation and temperature is illustrated in Figure 2 using long-term Weather Bureau records for Lake Arrowhead and Big Bear Lake Dam. Although Big Bear Lake is higher (Elev. 2078 m) and colder (mean annual air temperature = 6.43 C) than Lake Arrowhead (Elev. 1587 m and mean annual air temperature = 11.05 C), it receives less average annual precipitation (934 mm) than Lake Arrowhead (1063 mm).

The mean annual precipitation measured or projected for a number of stations maintained by the San Bernardino Flood Control District is shown in Table 1 in relation to nearby study plots and their elevations. The mean annual precipitation does not increase uniformly with elevation in the area because of the configuration of the mountains and its effect upon the movement of air masses and subsequent occurrence of rain shadows. The long-term precipitation estimates indicate that the plots near Lake Arrowhead (DWA, UCC, and SF) receive the greatest precipitation, while those at the eastern end of the study area receive

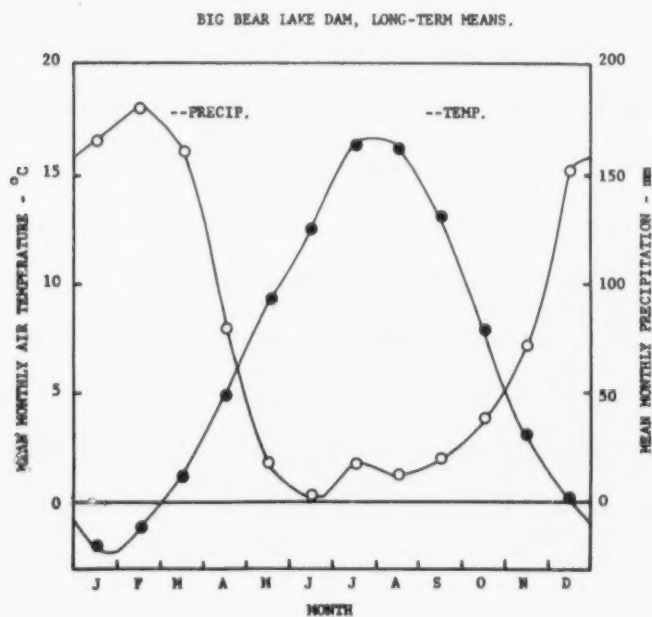
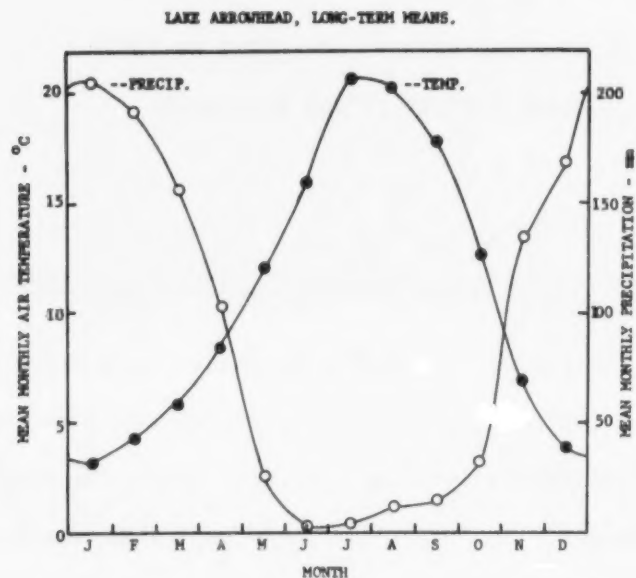


Figure 2. Long-term Weather Bureau records for monthly means of temperature and precipitation at Lake Arrowhead and Big Bear Lake Dam.

TABLE 1. COMPARISON OF MEASURED AND PROJECTED MEAN ANNUAL PRECIPITATION FROM SAN BERNARDINO COUNTY FLOOD CONTROL DISTRICT STATIONS NEARBY THE PERMANENT VEGETATION STUDY PLOTS

Station	Elev. (meters)	Nearest Major Vegetation Plots	Direction and Distance (km) of station from major Vegetation Plot	Mean Annual Precip. (mm)	Years of Record
Cedar Pines Park	1448	CP	1.6 N	579 <u>a/</u>	6
Job's Peak	1573	BP	1.5 W	707 <u>a/</u>	7
Blue Jay Co. Yard	1646	DWA	1.0 NNW	1073 <u>a/</u>	4
Lake Arrowhead	1587	UCC	1.6 S	1063	35
Arrowhead RS	1705	SF	0	1112 <u>a/</u>	13
Running Springs	1854	COO	3.2 SE	960	21
Green Valley Lake	2098	NEGV	1.6 WSW	829 <u>b/</u>	6
		GVC	2.4 ENE		
Big Bear Lake Dam	2078	BL	2.4 N	934	33
Big Bear Lake Fire Station	2056	HV	5.2 S	570	24
Big Bear City	2073	SC	6.4 N	301 <u>c/</u>	13
Green Canyon Springs	2134	SC	2.4 E	331 <u>c/</u>	10
Heart Bar	2039	HB	0	389 <u>c/</u>	7
Camp Angelus	1762	CA	0	750 <u>c/</u>	5

a/ Long term mean projected from Lake Arrowhead by linear regression

b/ Long term mean projected from Running Springs by linear regression

c/ Long term mean projected from Big Bear Lake Fire Station by linear regression

Correlation coefficients for linear regression are highly significant with values at least 0.92, where 1.0 represents a perfect correlation.

the least (HB and SC). However, two years of data collected with snow storage gauges at each plot (Table 2), indicate that Holcomb Valley north of Big Bear Lake receives low precipitation, while Bluff Lake plot south of Big Bear Lake on a high plateau area receives more precipitation than any other plot. The long-term means shown in Table 1 may be compared with 1973-1974, and 1974-1975 precipitation measured at each vegetation plot, Table 2. An improved precipitation map for the SBNF can now be constructed from these data.

Precipitation variability across the transect of study plots might have implications for the degree of oxidant injury to vegetation. Analysis of this possible interaction is in progress at present and further discussion can be found in that section of this report under: The Climate in the Soil and the Drought Stress.

Topography, Meteorology, and Pollutant Transport

The San Gabriel and San Bernardino Mountains surround the northern and eastern limits of the Los Angeles Basin and connected inland valleys now designated the South Coast Air Basin. Studies by Edinger et al. (1972) described the daily inland flow of polluted air on typical summer days along a sample path from the coast at Santa Monica to Redlands and north (upslope) to the mountain crest (Figure 3). The marine temperature-inversion air layer, extending inland across the heavily urbanized Los Angeles metropolitan area, frequently remains intact as far as 144 km (90 miles) inland, depending on time of day and season. The intact inversion air layer usually contacts the mountain slopes below 1216 m (4,000 ft.) elevation. Surface heating of air under the inversion

TABLE 2. WINTER PRECIPITATION, 1973-1974, AND 1974-1975, AT EACH MAJOR VEGETATION PLOT, SAN BERNARDINO NATIONAL FOREST, DETERMINED BY SNOW STORAGE GAUGES, SEPTEMBER 15 TO MAY 1.

Plot	Precipitation ^a (cm)		Precipitation ^a (inches)	
	1973- 1974	1974- 1975	1973 1974	1974- 1975
CP	45.6	48.5	18.0	19.1
BP	99.0	76.9	39.0	30.3
TUN 2	85.6	64.1	33.7	25.2
UCC	80.8	49.4	31.8	19.4
DWA	--	83.6	--	32.9
SF	106.9	79.5	42.1	31.3
COO	81.1	68.5	31.9	27.0
GVC	71.8	59.3	28.3	23.3
NEGV	73.3	54.8	28.9	21.5
SV	77.0	--	30.3	--
DL	--	78.2	--	30.8
HV	39.7	30.8	15.6	12.1
BL	134.8 ^b	68.9	53.1 ^b	27.1
SC	35.1	31.1	13.8	12.2
CA	38.6	61.6	15.2	24.2
SCR	39.5	47.2	15.6	18.6
BF	40.1	40.9	15.8	16.1
CAO	43.1	35.1	17.0	13.8
HB	37.8	32.9	14.9	12.6

^a All data calculated by formula using individual snow gauge dimensions.

^b Apparently much too large, snow probably drifted over the snow gauge.

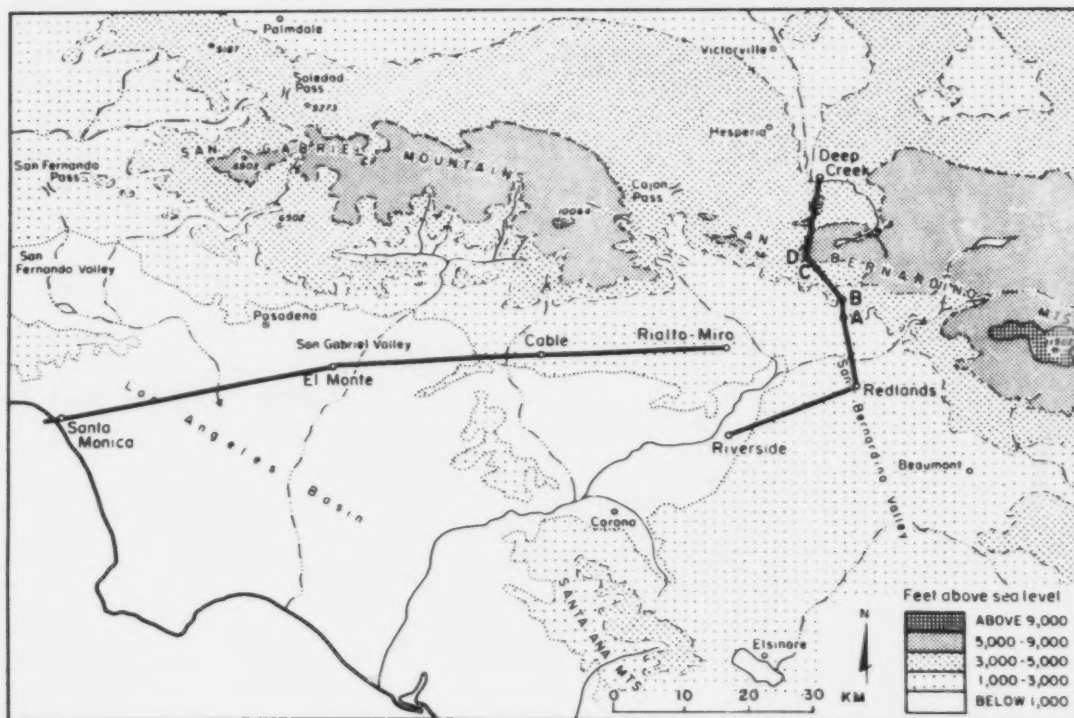


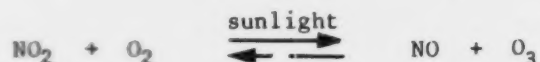
Figure 3. Major topographic features of the Los Angeles Basin showing aircraft flight routes (solid lines) and ground stations (A,B,C,D) used by Edinger et al. (1972) to describe the daily inland and upslope flow of polluted air.

tends to disrupt the inversion layer particularly along its inland extent. The heated mountain slopes act as a chimney to vent oxidant air pollutants over the forested crest toward the desert beyond, (Figure 4). Both an instrumented aircraft and ground monitoring stations (A, B, C, and D, Figure 3), documented the diurnal changes in oxidant concentrations on the mountain slope and crest, (Edinger et al. 1972). Edinger (1973) also described how part of the upslope flow of pollutants may be injected horizontally away from the slope



Figure 4. Daily increase of upslope advection at 1200 (top), 1400 (middle), and 1600 hr (lower), from the basin (left) across the Lake Arrowhead area (right mid-ground).

and back southward into the stable inversion layer. As a result, on many days the inversion itself serves as a reservoir for oxidants which may arrive later at downwind locations along the mountain slopes and crests. Oxidants remain relatively undiluted owing to lack of vertical mixing within the inversion layer and lack of contact with fresh infusions of nitric oxide (NO):



This phenomenon results in prolonged high concentrations of oxidants at night in the mountains. Ground station "D", Figure 3, is located near Rim Forest and Sky Forest at 1657 m (5450 ft) and will be referenced frequently in a following section describing variations of oxidant concentrations during the growing season.

The annual cycle of photochemical oxidant concentrations as illustrated by data collected at Sky Forest in 1973 and 1974 (Figure 5), bears a remarkable resemblance to the mean monthly changes of air temperature (Figure 2). The average of the maximum hourly averages for total oxidant remains near the world-wide background concentration of 0.03-0.04 ppm only in December and January. By the middle of May, when new leaves emerge on black oak, and pines begin new needle growth at Sky Forest, the daily pollutant episodes far exceed Federal Air Quality Standards (Appendix A). According to Figure 48, the soil moisture available for plant roots is generally depleted at depths down to 2.7 m by the middle of August.

The difference in the time of occurrence of high oxidant concen-

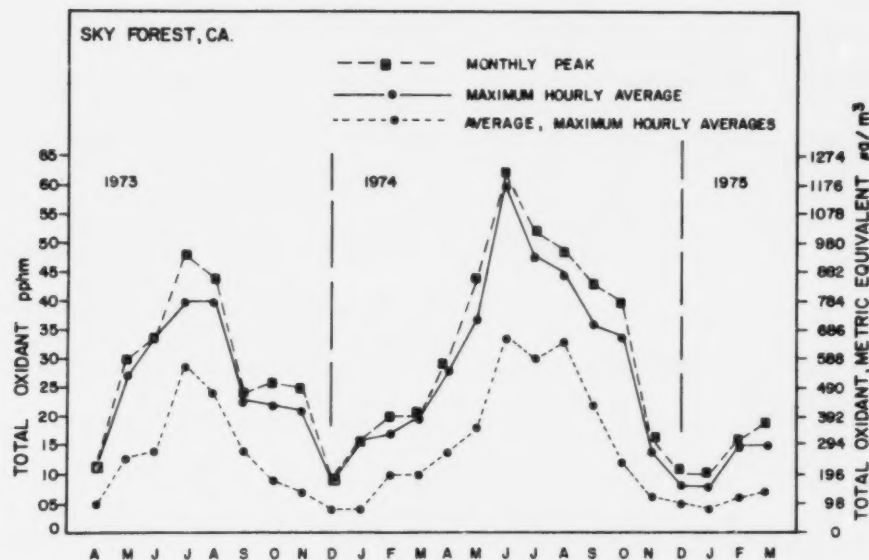


Figure 5. The annual cycle of monthly photochemical oxidant concentrations at Sky Forest, California, 1973-1975.

trations (Figure 5) suggests a lower dose during the period of maximum water availability in 1973 and higher doses during this period in 1974. The meaning of this difference to the occurrence and amount of vegetation injury is a central question which must be thoroughly explored. Early results comparing injury in 1973 and 1974 (Tables 6 and 7) at all vegetation plots suggest more injury in 1974. These relationships will be discussed further in the following sections.

SOILS

Soils of the various vegetation plots under investigation were characterized with respect to their chemical and physical properties in order to find relationships between soil properties and the susceptibility of the vegetation to air pollutant damage, and to begin the search for possible soil changes resulting from the effects of air pollutants.

The soils were classified according to "Soil Taxonomy" (Soil Survey Staff, USDA) in order that the results from this entire project can be suitably projected to similar soils of other areas, primarily by other soil scientists. The particle size distribution (soil texture) was measured because of its importance as an indicator of the ability of the soils to store water and nutrients for plant use. The bulk density was measured because of its affect upon root penetration and distribution, and its relationship to soil porosity and permeability to water and air. Exchangeable and soluble cations and the pH of the soils were measured as they relate to the mineral nutrient status of the soils; soil organic matter likewise affects the structure, water retention, and porosity of the surface soil, and is a source of nitrogen for plants and energy for microorganisms, including pathogens. The water storage capacity of the soil is particularly important in this area because of the long, dry, warm summer during which the plants are almost entirely dependent upon stored soil moisture for their survival. Finally, the amount of organic litter (needles and woody material) on the forest floor is related to

the vigor of the forest and the production of the litter in relation to its decomposition rate. It also directly affects seed germination, seedling survival, and soil temperature, moisture, and humus content.

Soil Classification for the San Bernardino Mountain Study Plots

Soils were examined at a number of sites in each of 18 plots. The parent material of the soils is partially weathered or decomposed granitic rock on all of these plots except for three which also include alluvial or colluvial material. Sand Canyon plot is on granitic rock at its eastern end, but the bulk of the plot is colluvium including some marble fragments derived from metamorphic rocks. It is located southeast of Big Bear Lake. Heart Bar plot is dominantly mixed alluvium derived from granitic and metamorphic rocks, and is located in the upper end of Santa Ana Canyon. Camp Angelus plot is mainly stony granitic colluvium, although the southern end of the plot is formed directly on granitic rock.

The granitic rock weathers first to decomposed granite gruss, then to coarse sand, loamy coarse sand, coarse sandy loam and eventually to sandy clay loam or clay textured soils if the weathering is sufficiently intense and of long duration. Above about 1800 m (6000 ft) in altitude, the mean annual soil temperature is low (mainly less than 8 C) with reduced weathering intensity, so that the soils are mainly coarse sandy loams, or loamy coarse sands, and without marked accumulation of clay in the subsoil. At lower elevations, soils in moist sites show some degree of clay accumulation in the subsoil, but only on the warmest sites on the desert (north) side of the crest are continuous areas of

soils with a sandy clay loam subsoil texture encountered. These plots are Tunnel Two, U.C. Conference Center, and Holcomb Valley.

Using observed properties of soil color, texture, structure and reaction (pH), the soils on the various plots were classified according to "Soil Taxonomy" (Soil Survey Staff, USDA) preliminary text and according to soil series names established by the National Cooperative Soil Survey for California: see Appendix B. The soils in the Lake Arrowhead region are dominantly of the Shaver series which is dark in color to a depth of greater than 50 cm (Pachic), slightly acid in the surface (Mollic), increasingly acid with depth (Ultic) and with no significant clay accumulation in the subsoil (Haplic). The texture of the subsoil is coarse sandy loam, classified as coarse loamy, the clay mineralogy for granitic soils is a mixture of kaolinite, mica, illite, and vermiculite. The mean annual soil temperature is between 8 and 15 C (Mesic), and the soils are continuously dry in the upper part for 90 days in summer (Xeric).

Thus the complete classification of the Shaver soil series is:

Order: Mollisol

Suborder: Xeroll

Great group: Haploxeroll

Subgroup: Pachic Ultic Haploxeroll

Family: Coarse, loamy, mixed, mesic

Soil series: Shaver.

The soils with distinct subsoil accumulation of clay, due to more intense and prolonged weathering on the Tunnel Two and U.C. Conference Center plots, differ in that on Tunnel Two, the surface is dark to a

depth of less than 25 cm, while on the other plot it is between 25 and 50 cm in depth. Consequently, the Stump Springs soil on Tunnel Two is an Ultic Haploxeralf, while U.C. Conference Center is an unnamed soil classified as an Ultic Argixeroll. At Holcomb Valley north of Big Bear Lake, are Typic Argixeroll soils of the Domingo Series, similar to those of the U.C. Conference Center, but not increasingly acid with depth.

The remaining soils are either of coarse sandy loam (coarse loamy), or loamy coarse sand (sandy) throughout the entire depth of soil, except for the Cahto variant soil at Camp Angelus which is stony, coarse sandy loam. Some are shallow (lithic), some are sandy (Psamments). Some have dark, acid surface soils and slightly bleached layers below (Umbrepts) or are not dark (Orthents and Ochrepts). Although Appendix Table B shows that there are some 23 soils represented on these plots, many are quite similar which makes it possible to compare the effects of air pollutants of varying concentration on vegetation growing on nearly identical soils in a number of cases.

Chemical and Physical Soil Morphology

In addition to the soil samples collected at 23 sites, morphological descriptions of soils at 62 sites were obtained on 18 plots. Information included horizon designation, texture, color, pH, and surface structure. Physical and chemical measurements also were made of 23 soils at the soil moisture sensor sites. These included particle size distribution, bulk density, gravel and stone content, pH, exchangeable and soluble cations, nitrogen and organic matter content. Only partially complete information could be obtained from the plots at

Camp Angelus, Barton Flat, and Camp Oseola because the stony nature of the soils there essentially precludes volumetric sampling. A total of 246 samples was analysed in this way. These data provide the basic information for relating the nature of the soil to the kind and amount of vegetation and its susceptibility to air pollution injury.

Particle Size Distribution

The content of sand, silt, clay, fine gravel and coarse gravel of selected soil samples from 17 study plots is shown in Appendix C. All values are given in percent of fine soil material, i.e. grams per 100 grams of soil material finer than 2.0 mm in effective diameter. The samples reported include the surface soil, a subsoil sample showing the maximum clay content and a deeper sample of minimum clay content at or near the base of the soil where it grades into decomposed granite.

The variation of particle size distribution with depth for 3 representative soils is shown in Figure 6. The soil labeled Unnamed-2 has a distinct maximum in clay content at a depth of 70 to 100 cm. Similar soils are found at Tunnel Two and at Holcomb Valley. The Shaver soil found on a number of plots in the Lake Arrowhead area between Camp Paivika and Sky Forest contains less clay and shows only a small and gradual decrease in clay content from the surface downward. The Crouch variant soil at Schneider Creek is representative of the sandier soils at Green Valley Creek, N.E. Green Valley, Heart Bar and Sand Canyon which contain little clay and considerable fine gravel. The soil at Bluff Lake is also sandy but contains little fine gravel.

As in most soils formed from granitic rock, these soils generally

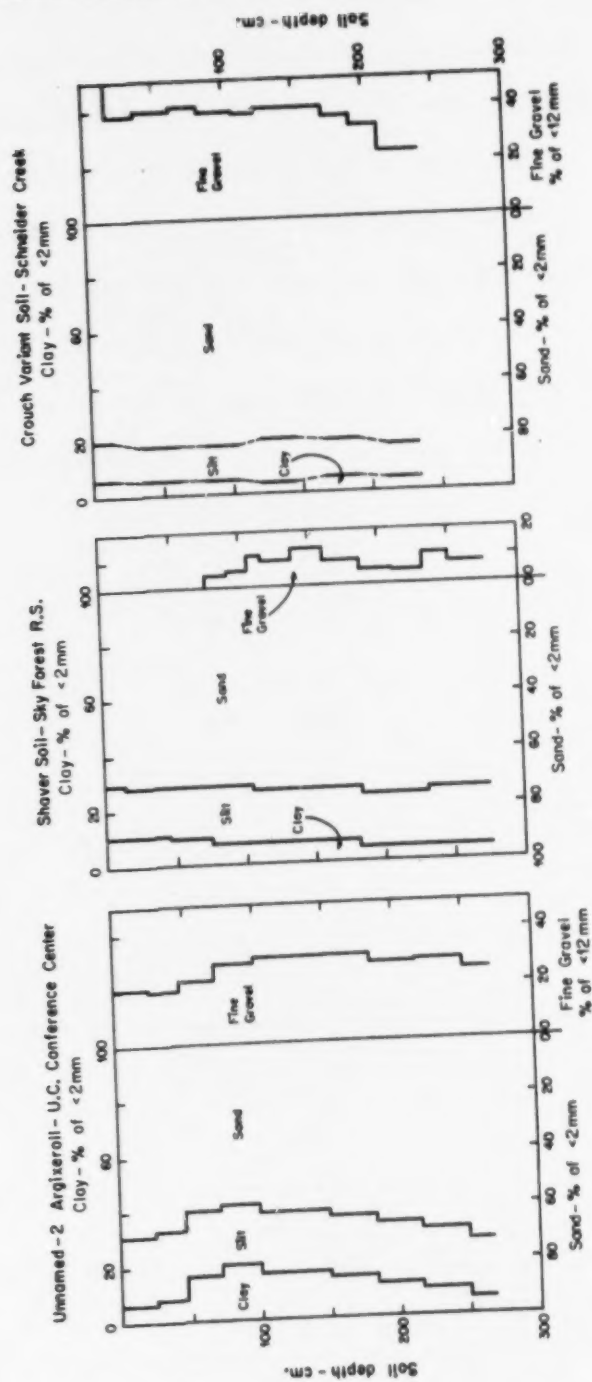


Figure 6. Three representative soil profiles of particle size distribution.

contain considerable fine gravel (2 to 12 mm in diameter) and as a consequence would technically be classified as gravelly. However, most of the fine gravel is about 2 to 4 mm in diameter and behaves much like very coarse sand in the soil, so the gravelly designation is omitted from the coarse sandy loam and loamy coarse sand textural classifications.

The average particle size distribution and the textural classification of the various soils is shown in Figure 7. This figure is only a portion of the textural triangle chart used by the U.S.D.A. Soil Conservation Service. As can be seen, the average texture of these

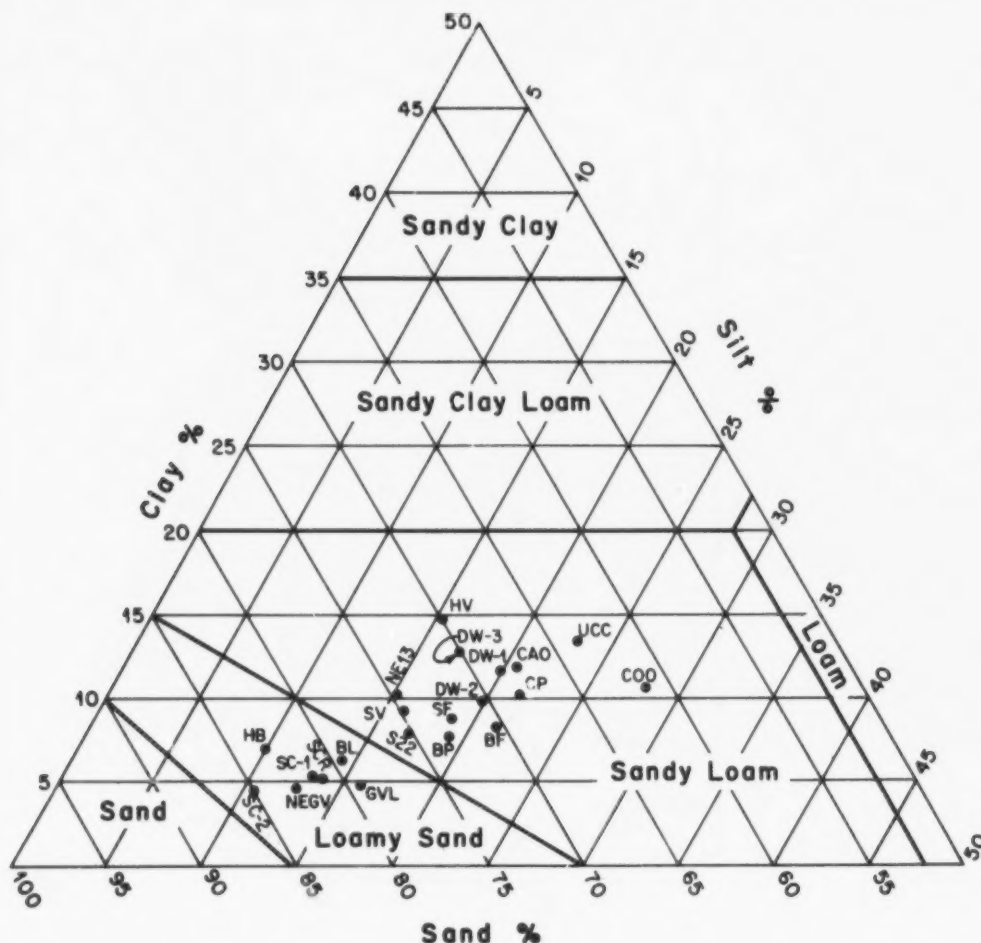


Figure 7. Average particle size distribution of soils of study plots.

soils are either loamy sands or sandy loams. The soils with loamy sand textures are all in plots located east of the Lake Arrowhead area near Green Valley and Big Bear Lakes and in the Santa Ana Canyon.

Bulk Density of Soils

The bulk density or volume weight of soils (D_b) was determined in connection with the moisture sampling. The variation of bulk density with depth is shown for eight representative soils in Figure 8. A complete set of data is given in Appendix D.

Of the surface soils, the one at Breezy Point (BP) is the least dense (0.74 gm/cm^3) and very rich in organic matter. The soils with the most dense surface soils are at Holcomb Valley (HV) and at the U.C. Conference Center (UCC) with bulk densities of more than 1.4 gm/cm^3 , which are soils also having clayey subsoils and are in the warmer north side of the general transects. Most of the soils have surface bulk densities of 1.1 to 1.3 gm/cm^3 , and are thus very porous and of good granular or crumb structure.

Subsoil densities are generally from 1.5 to 1.7 gm/cm^3 which is very common for soils of sandy textures. The higher bulk densities are associated with loose sandy soils which tend to crumble into the sampling hole, so that those greater than 1.8 gm/cm^3 may well be due to sampling error. Notice that again the Breezy Point soil (BP) has a low density to considerable depth; this soil also has the highest available water storage capacity as indicated in Appendix H.

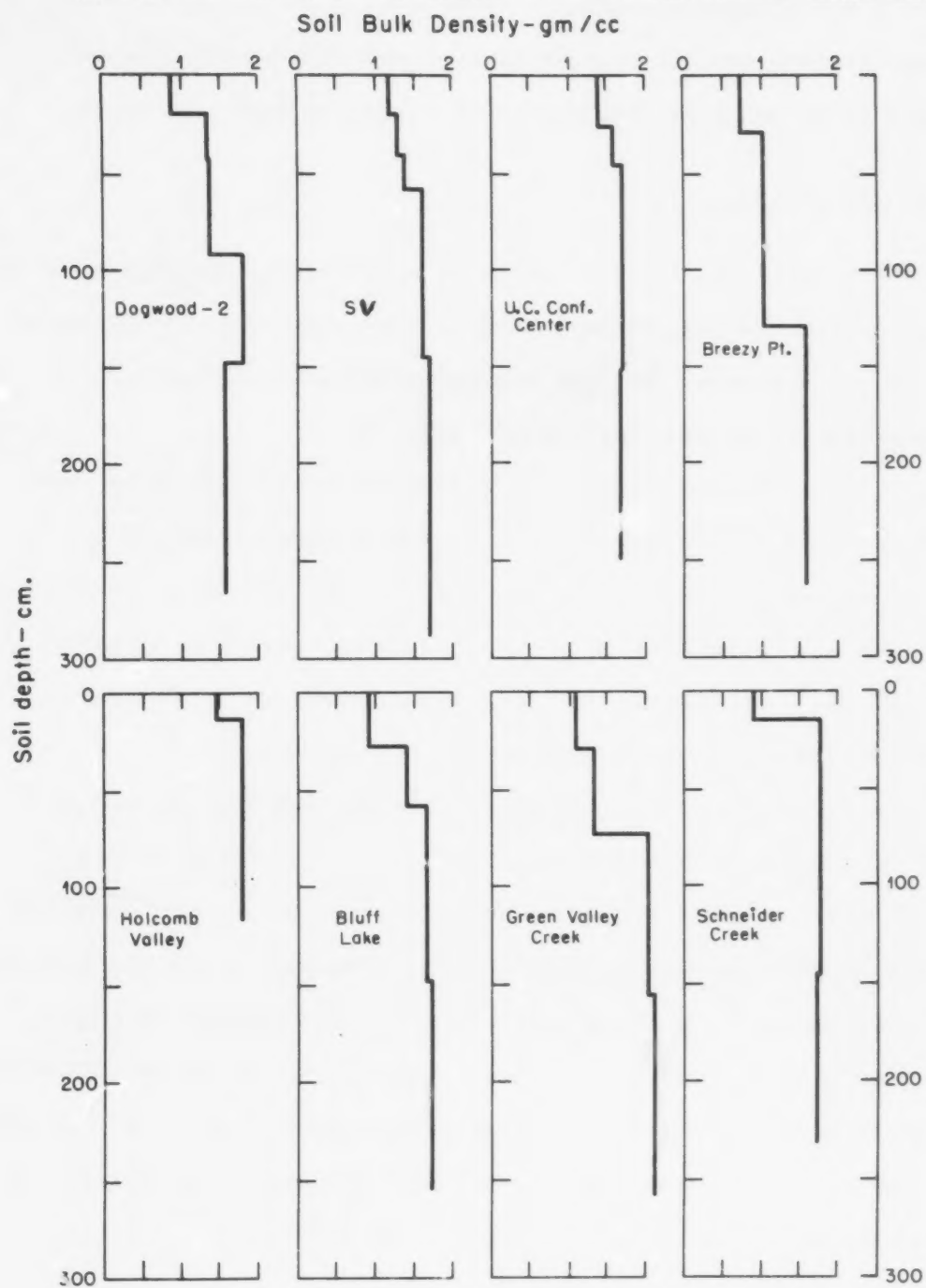


Figure 8. Representative soil bulk density profiles on study plots.

Exchangeable and Soluble Cations

Exchangeable and soluble cations were determined on 22 soils throughout their total depths on the vegetation plots (omitting Camp Angelus, and including two other sites at S22 and NE13) making a total of 251 samples. Soluble cations were determined on a 1:1 water extract of the soil, and exchangeable cations on a neutral 1.0 normal ammonium acetate extract.

The results for surface soils are shown in Appendix E. The dominant exchangeable cation is calcium (Ca) with magnesium (Mg), potassium (K) and sodium (Na) decreasing in that order. The values obtained are quite typical of surface soils formed on granitic rocks elsewhere in California (Soil Survey Staff USDA, unpublished document). For example the common range for exchangeable calcium is from 5.0 to 10.0 meq/100 g. Thus the soil at site 3 on the Dogwood plot (DW-3) and that at Bluff Lake (BL) are low in calcium, the latter due to its cold, humid climate. At Sand Canyon, the (SC) surface soil is rich in calcium probably due to its proximity to the ridge above which contains some marble, but exchangeable potassium content is quite low.

Soluble cations in the surface soil likewise are dominated by calcium followed by potassium, magnesium and sodium in that order. These again are in concentrations often found in granitic soils. All except Sand Canyon site 1 (SC-1) appear to contain adequate supplies of these elements for plant growth.

Exchangeable and soluble cations for representative subsoil layers from the same soils are shown in Appendix F. Again the soils at DW-3

and BL are low in cations, especially at BL. High values of exchangeable calcium are shown for Holcomb Valley (HV) and U.C. Conference Center (UCC) both of which have pronounced clay accumulations in the subsoil. A number of the values for exchangeable and soluble potassium are low (less than 0.1 and less than 0.005 meq/100 gm) respectively. However, the complete data indicate that soluble potassium is low throughout the entire depth of soil only in Bluff Lake (BL), Sand Canyon site 1 (SC-1), and Green Valley Creek (GVC).

Soil Organic Matter

Organic carbon and nitrogen were determined on samples from major plots to a depth of 50 or 60 cm. The results for the upper 25 cm of soil only are shown in Appendix G. The soils with the most organic matter are shown to be at Dogwood-3, Bluff Lake and Barton Flat with organic carbon values of 2.99 g/100 g or more. Soils with the least organic matter are Sand Canyon-1, Green Valley Creek and Heart Bar, all of which have relatively thin needle-litter layers on the soil. The highest value for nitrogen was found at Camp O-Ongo, but the unusually low ratio of carbon to nitrogen (C/N) suggests possible contamination, perhaps by riding horses from the nearby summer camp. Other sites with high nitrogen levels are at Bluff Lake, Barton Flat, Dogwood-3 and Breezy Point. C/N ratios generally range from 20 to 30 which are common under mixed conifer forests.

Soil Water Available for Vegetation Growth

In order to quantify the soil moisture regimes in terms of total

quantities of water, the soils at the 23 sites were sampled volumetrically for gravimetric measurement of total water content both in April when full wet, and in October, when at minimum moisture content. The difference is assumed to be the amount of water available to the plants, assuming that the organic litter layer on the surface limits air movement and thus limits direct evaporation from the soil to very low levels. The values obtained by this procedure are shown in Appendix H. Included are only those plots in which the soils were sufficiently low in stone and gravel content to permit volumetric sampling. The first 3 columns of data show the volumetric percent and the total calculated depth of available water in April to a uniform depth of 152 cm (5 ft). The last two columns show the total soil depth and the total available water storage. The most significant fact shown by these data is that the available soil moisture storage values within the root zone of the pine forest is very high, about 30 cm (12 inches) or more, compared to the values commonly used in water balance studies of this kind (10 or 15 cm). The low values found for the last five plots listed, may underestimate the water available to the trees, which may be obtaining water from the firm weathered granite below the depth of sampling; perhaps from cracks and joints in the rock.

Amounts of Organic Litter on the Forest Floor

In order to document the status of accumulated organic matter (pine needles, twigs etc.) on the forest floor of the various study plots in relation to the impact of air pollutants on the pine forest, the thickness of the litter layer was measured at 2 m intervals along

a line transect for the length of the plots. In addition, core samples of the litter layer were collected at 135 representative sites, in order to establish the relationship between mass and thickness of the layer (T) in cm.

Regression analysis of the latter showed that:

$$\text{Mass (Kg/m}^2\text{)} = 1.249 T + 1.329$$

The correlation coefficient was 0.902, and the regression line was not significantly different from one passing through the origin ($T = 0$, $\text{Mass} = 0$) which gave the relationship:

$$\text{Mass} = 1.41 T$$

Using the latter, the average amount of the litter on the forest floor was calculated from the average thickness measured. However, it was found that the litter layer on the forest floor on some plots had been stripped away by recreation and logging activities, and in order to obtain meaningful averages, these areas were treated separately.

The results are shown in Table 3. It can be seen that the thickest forest floor was found on undisturbed areas of Dogwood, Sky Forest (Figure 9), U.C. Conference Center, Camp Paivika, Breezy Point and Camp Angelus. Relatively thin layers were found on undisturbed plots at Snow Valley (Figure 9), N.E. Green Valley and Holcomb Valley, but none of these were as thin as the disturbed areas of Dogwood, Green Valley Creek, Holcomb Valley and Camp Osceola. The very marked reduction in thickness of the forest floor by recreation activities (mainly by motorcycles) and by logging (even scattered sanitation logging removing oxidant-injured or insect-infested trees) may have important conse-

TABLE 3. MASS AND THICKNESS OF THE FOREST FLOOR ON MAJOR STUDY PLOTS.

Plot	Sample Size Number	Mean Thickness, T (cm)	Standard Deviation of T	Mass ^a (Kg/m ²)	Standard Deviation of mass
DWA (disturbed)	20 (66)	12.5 (2.8)	+1.23 (+0.42)	17.61 (3.92)	+1.73 (+0.59)
SF	102	10.7	+0.43	15.11	+0.61
UCC	32	11.1	+1.03	15.73	+1.45
CP	76	10.3	+0.48	14.52	+0.68
BP	49	9.4	+0.50	13.23	+0.71
TUN 2	81	8.4	+0.54	11.8	+0.76
COO	84	7.5	+0.43	10.56	+0.61
GVC (disturbed)	20 (60)	8.4 (3.3)	+0.54 (+0.34)	11.81 (4.71)	+0.76 (+0.48)
NEGV	127	5.3	+0.3	7.47	+0.47
SV	138	4.2	+0.39	5.91	+0.55
HV (disturbed)	77 (52)	5.2 (1.3)	+0.42 (+0.19)	7.32 (1.84)	+0.59 (+0.27)
BL	110	6.6	+0.39	9.35	+0.55
CA	74	9.8	+0.55	13.75	+0.78
CAO (disturbed)	62 (24)	6.6 (2.6)	+0.40 (+0.29)	9.27 (3.65)	+0.56 (+0.41)
Range (undisturbed)		4.2/12.5		5.91/17.61	

^a Calculated mass = 1.41 T

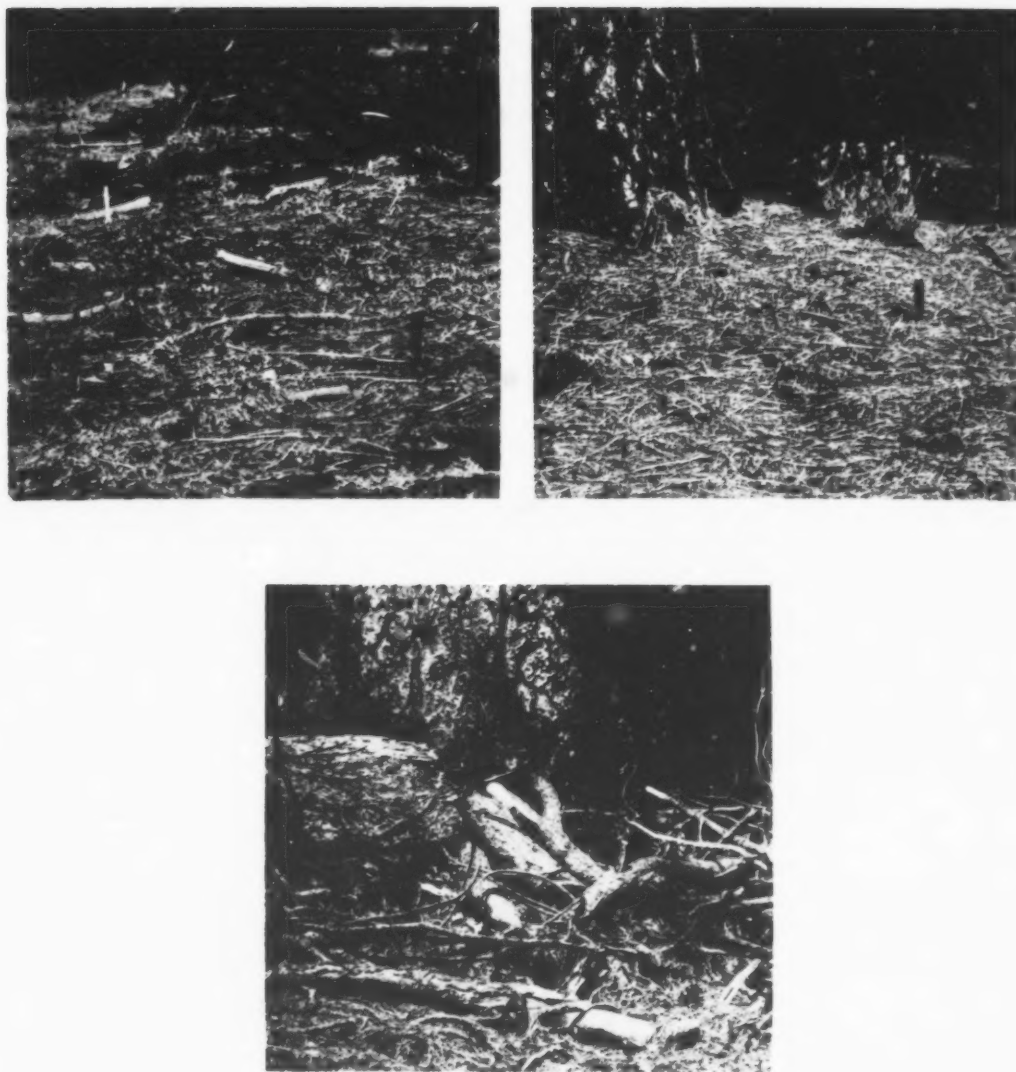


Figure 9. Comparison of thicker forest floor litter at Sky Forest (upper left) with Snow Valley (upper right), and an example of excessive litter and heavy fuel accumulation at Sky Forest (lower).

quences with respect to seed germination, seedling survival, soil temperature and moisture, animal habitats and fire behavior.

On the other hand, the accumulated needle litter, fallen (unharvested) trees killed by the oxidant injury-bark beetle complex, and the accumulated slash from repeated sanitation salvage logging have resulted in serious fuel overloads at places like Sky Forest (Figure 9). The implication is that wildfires could cause the death of even large trees because of sustained high temperatures.

VEGETATION

Importance

The vegetation of the San Bernardino Mountains is a valuable resource for the people of the United States. It provides a setting for recreation, commodity products such as lumber and forage, and essential watershed protection. The vegetation is also an integral component of the natural ecosystems that occur in the San Bernardino Mountains. Oxidant air pollutants, arising from the urban areas to the south and east of the San Bernardino Mountains, are injurious to the vegetation. The impact of this injury has important consequences to both man's use of the vegetation and to the functioning of the natural ecosystem. An understanding of the impact on vegetation can come about through an evaluation of vegetation and its successional potential along gradients of oxidant air pollution. The impact of pollution on the natural ecosystem can be understood if knowledge of the interactions of vegetation, other ecosystem components, and air

pollutants is available.

Vegetation Zones

The vegetation of the San Bernardino Mountains is composed about equally of chaparral and forest types with important minor elements of woodland, sagebrush, and grassland. Horton (1960) and Minnich et al. (1969) have undertaken major treatments of this vegetation. Horton (1960) recognized six vegetation zones on the basis of plant physiognomy and environmental conditions (Figure 10): Chamise-chaparral, woodland-chaparral, desert chaparral, pinyon-juniper woodland, timberland chaparral, and coniferous forest. One or more vegetation types occur within each zone. Twenty of these types were defined by Horton (1960) on the basis of field reconnaissance. Minnich et al. (1969), using infrared color imagery on aerial photographs, mapped 28 vegetation types in the San Bernardino Mountains. The relationship between the vegetation types recognized by the two authors is indicated in Appendix I.

Vegetation Types

Our study has focused on the Coniferous Forest Zone. This zone ranges in elevation from 1524 m to 1981 m on the north facing slopes and 1524 m to 2286 m on south facing slopes upwards to the highest peaks (San Gorgonio, 3,505 m). Four coniferous forest vegetation types were recognized by Horton (1960) in this zone. Two of these types, Pine Forest and Ponderosa Pine-White Fir Forest, have been the central concern of this study. An improved map has been prepared based on a

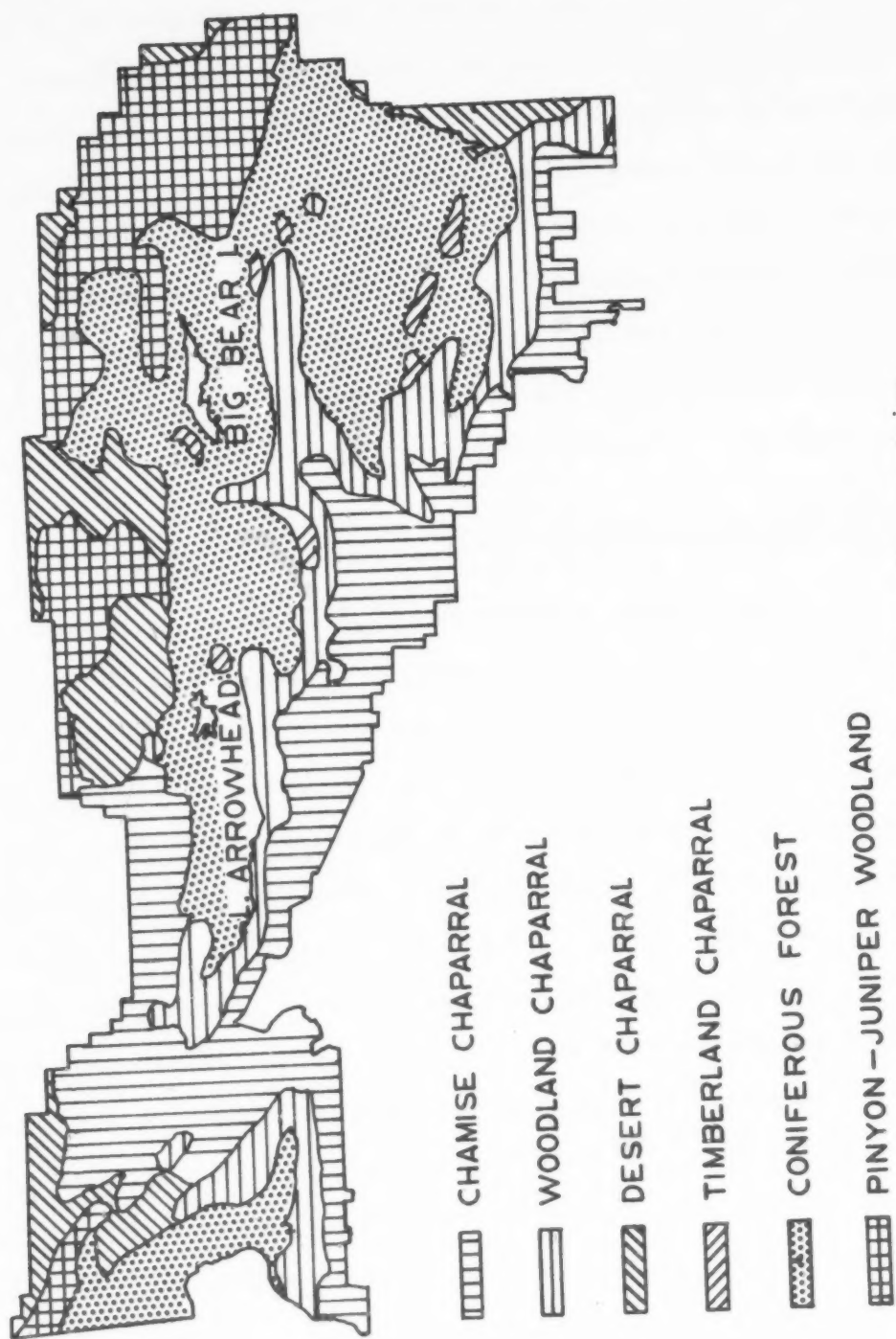


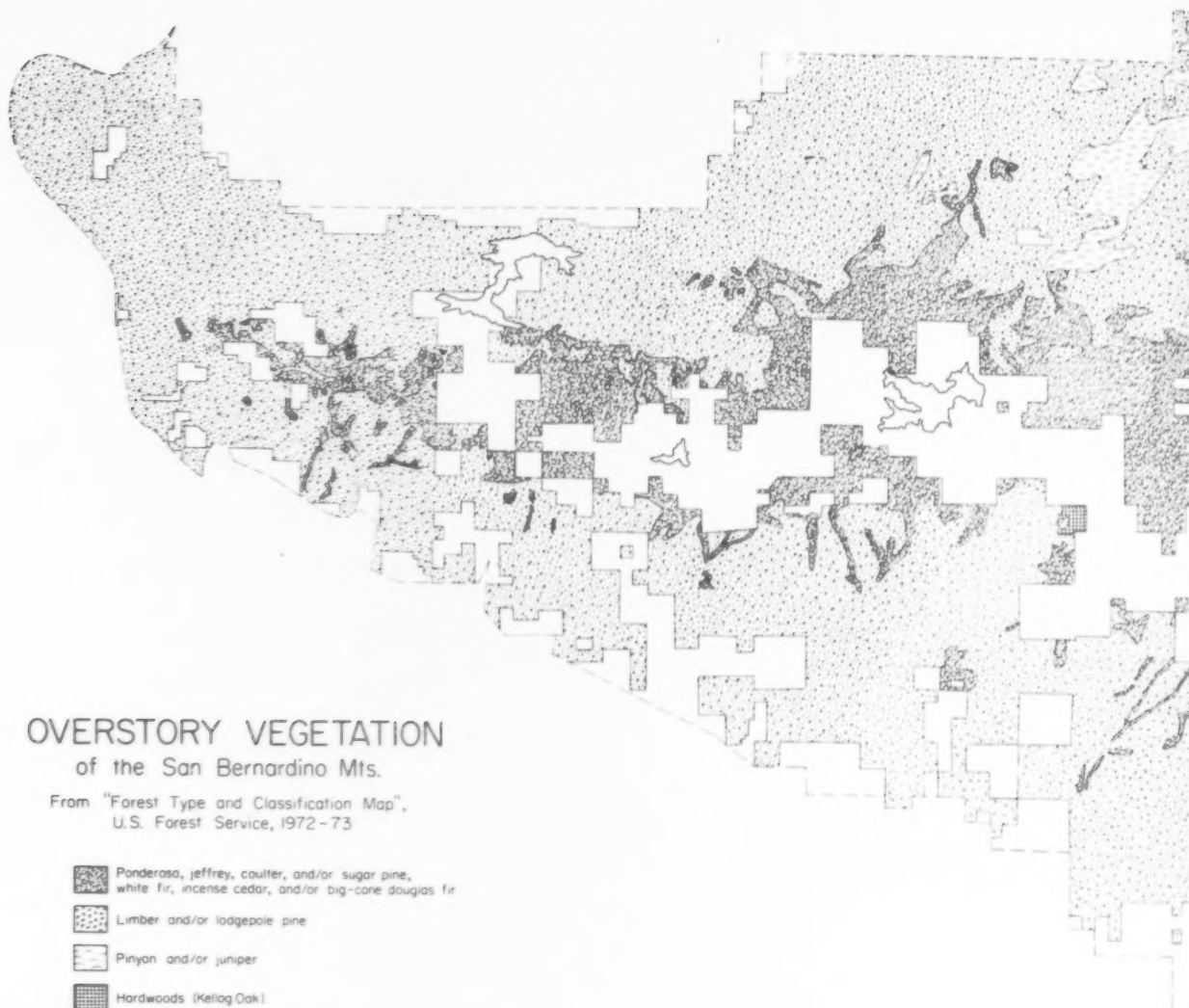
Figure 10. Vegetation zones of the San Bernardino mountains.

U.S. Forest Service (1973) type map to show the distribution of these types (Figure 11). Our work has indicated that these two general types may be further subdivided into five vegetation types on the basis of species dominance. These types are as follows: Ponderosa Pine Forest, Ponderosa Pine-White Fir Forest, Ponderosa Pine-Jeffrey Pine Forest, Jeffrey Pine Forest, and Jeffrey Pine-White Fir Forest. Forest vegetation types dominated by ponderosa pine are distributed mainly in the western half of the San Bernardino Mountains, while Jeffrey pine dominated types occur more frequently in the eastern half (Figure 12).

Study Plots Within Vegetation Types

The vegetation subcommittee participated in the establishment of 18 permanent study plots in the San Bernardino Mountains (Figure 1). A nineteenth study plot, Deer Lick, was recently added, but results presented in this report refer only to the first eighteen plots. The first criterion for the selection of the location of these plots was species composition. Stands were selected in which either ponderosa or Jeffrey pine was dominant. Additional selection criteria included tree size, topographic position, parent material, and position along the oxidant gradient (Taylor, 1974). The descriptive characteristics of the vegetation on these plots have been analyzed by the vegetation subcommittee (McBride, 1974). The quadrat method (Clements, 1905) was used to determine density and cover in the tree and herb layers, while the line intercept method (Canfield, 1941) was employed in measuring characteristics of the shrub layer.

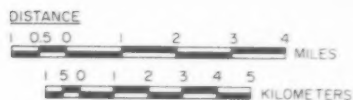
Figure 11. Overstory vegetation type map of the San Bernardino Mountains.



OVERSTORY VEGETATION of the San Bernardino Mts.

From "Forest Type and Classification Map",
U.S. Forest Service, 1972-73

-  Ponderosa, jeffrey, coulter, and/or sugar pine, white fir, incense cedar, and/or big-cone douglas fir
-  Limber and/or lodgepole pine
-  Pinyon and/or juniper
-  Hardwoods (Keliog Oak)
-  Unstocked or noncommercial sites, barren and waste areas, and/or chapparal
-  Private land within national forest boundary and/or lakes
-  Heart Bar State Park
-  San Geronio Wilderness area





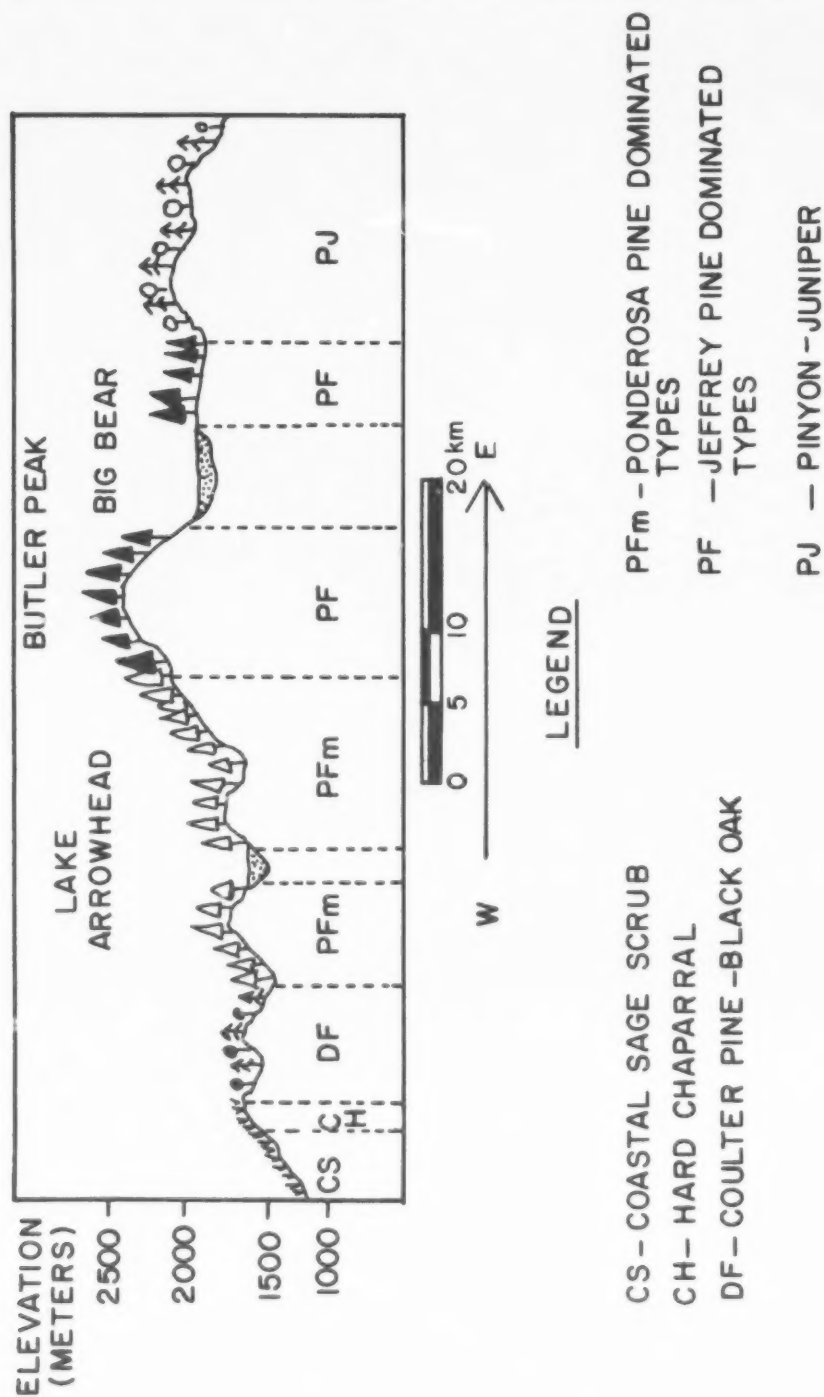


Figure 12. East-West distribution of vegetation types in the San Bernardino Mountains.

Tree Layer Data ---

Five plots, each representative of one vegetation type, are summarized in Table 4. Similar data from the remaining plots is available in the Task D Report (McBride, 1974). Species composition in the tree layer of each plot is illustrated in Figure 13. The Camp Paivika plot is typical of the Ponderosa Pine Forest type, Figure 14. Ponderosa pine makes up 57.9% of the composition of the plot. Black oak is a common species in the Ponderosa Pine Forest type and makes up 41.6% of the tree composition on this plot. The Ponderosa Pine-White Fir Forest type occurs on the Sky Forest plot, Figure 14. Here, ponderosa pine makes up 46.9% of the tree composition with white fir contributing 30.2%. Other tree species on the Sky Forest plot include sugar pine, incense cedar, black oak, and dogwood. The Barton Flats plot is representative of the Ponderosa Pine-Jeffrey Pine Forest type, Figure 13. Ponderosa pine contributes 55.9% of the tree composition of the plot while Jeffrey pine contributes 34.5%. The remaining 9.6% is contributed by black oak and interior live oak. The Jeffrey Pine-White Fir Forest type occurs on the Green Valley Creek plot, Figure 13. Here 19% of the composition is due to Jeffrey pine and 30.3% to white fir. Other species occurring on the Green Valley Creek plot are sugar pine, incense cedar, black oak, and interior live oak. The Jeffrey Pine Forest type is well developed on the Snow Valley plot, Figure 13. Jeffrey pine makes up 96.2% of the tree composition on this plot.

Shrub and Herb Layers ---

The vegetation of each of 19 permanent plots can also be further

TABLE 4. TREE LAYER DATA FROM PLOTS REPRESENTATIVE OF EACH VEGETATION TYPE DOMINATED BY PONDEROSA OR JEFFREY PINE IN THE SAN BERNARDINO MOUNTAINS.

Characteristics				
Mixed conifer forest types ^a	# trees ^b	Spp. Comp. ^c	Density ^d	Basal Area ^e
<u>Ponderosa Pine</u> (N.W. Paivika)				
PP	98	57.9	217.8	24.11
SP	1	0.5	2.2	0.03
IC	--	--	--	--
WF	--	--	--	--
JP	--	--	--	--
BO	70	41.6	155.6	6.32
QW	--	--	--	--
DW	--	--	--	--
Total	169	100	375.6	30.46
<u>Ponderosa Pine -</u> <u>White Fir</u> (Sky Forest)				
PP	104	46.9	144.4	28.38
SP	15	6.8	20.8	0.60
IC	25	11.2	34.7	4.10
WF	67	30.2	93.1	3.85
JP	--	--	--	--
BO	7	3.1	9.7	2.21
QW	--	--	--	--
DW	4	1.8	5.6	--
Total	222	100	308.3	39.14
<u>Ponderosa Pine -</u> <u>Jeffrey Pine</u> (Barton Flats)				
PP	139	55.9	200.1	16.87
SP	--	--	--	--
IC	--	--	--	--
WF	--	--	--	--
JP	86	34.5	123.8	10.21
BO	16	6.4	23.0	5.99
QW	8	3.2	11.6	0.56
DW	--	--	--	--
Total	249	100	358.5	33.63

TABLE 4. TREE LAYER DATA FROM PLOTS REPRESENTATIVE OF EACH VEGETATION TYPE DOMINATED BY PONDEROSA OR JEFFREY PINE IN THE SAN BERNARDINO MOUNTAINS. (Continued)

Mixed conifer forest types ^a	# trees ^b	Spp. Comp. ^c	Density ^d	Basal Area ^e
<u>Jeffrey Pine -</u>				
<u>White Fir</u>				
(Green Valley Cr.)				
PP	--	--	--	--
SP	11	5.4	12.2	2.93
IC	10	4.9	11.1	1.63
WF	62	30.3	68.9	4.94
JP	39	19.0	43.3	12.20
BO	82	40.0	91.1	4.70
QW	1	0.4	1.1	0.02
DW	--	--	--	--
Total	205	100	227.7	26.42
<u>Jeffrey Pine</u>				
(Snow Valley)				
PP	--	--	--	--
SP	--	--	--	--
IC	--	--	--	--
WF	3	2.9	3.9	1.30
JP	99	96.2	129.4	21.56
BO	1	0.9	1.3	0.16
QW	--	--	--	--
DW	--	--	--	--
Total	103	100	134.6	23.02

TABLE LEGEND:

^a Symbol	Common Name	Scientific Name
PP	ponderosa pine	<u>Pinus ponderosa</u>
SP	sugar pine	<u>Pinus lambertiana</u>
IC	incense cedar	<u>Libocedrus decurrens</u>
WF	white fir	<u>Abies concolor</u>
JP	Jeffrey pine	<u>Pinus jeffreyi</u>
BO	black oak	<u>Quercus kelloggii</u>
QW	interior live oak	<u>Quercus wislizenii</u>
DW	dogwood	<u>Cornus nuttallii</u>

^b Number of trees on the plot

^c Percent species composition on the basis of number of trees

^d Number of trees/hectare

^e Basal area in square meters/hectare

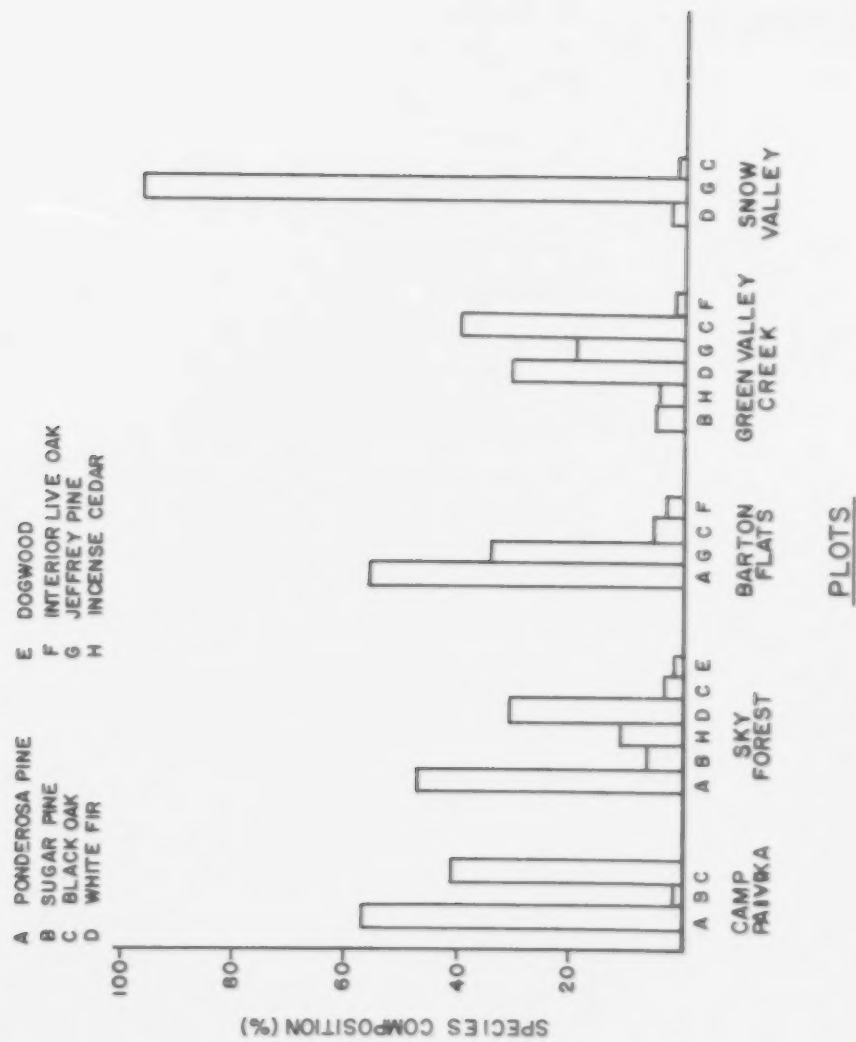


Figure 13. Tree species composition of five permanent plots.

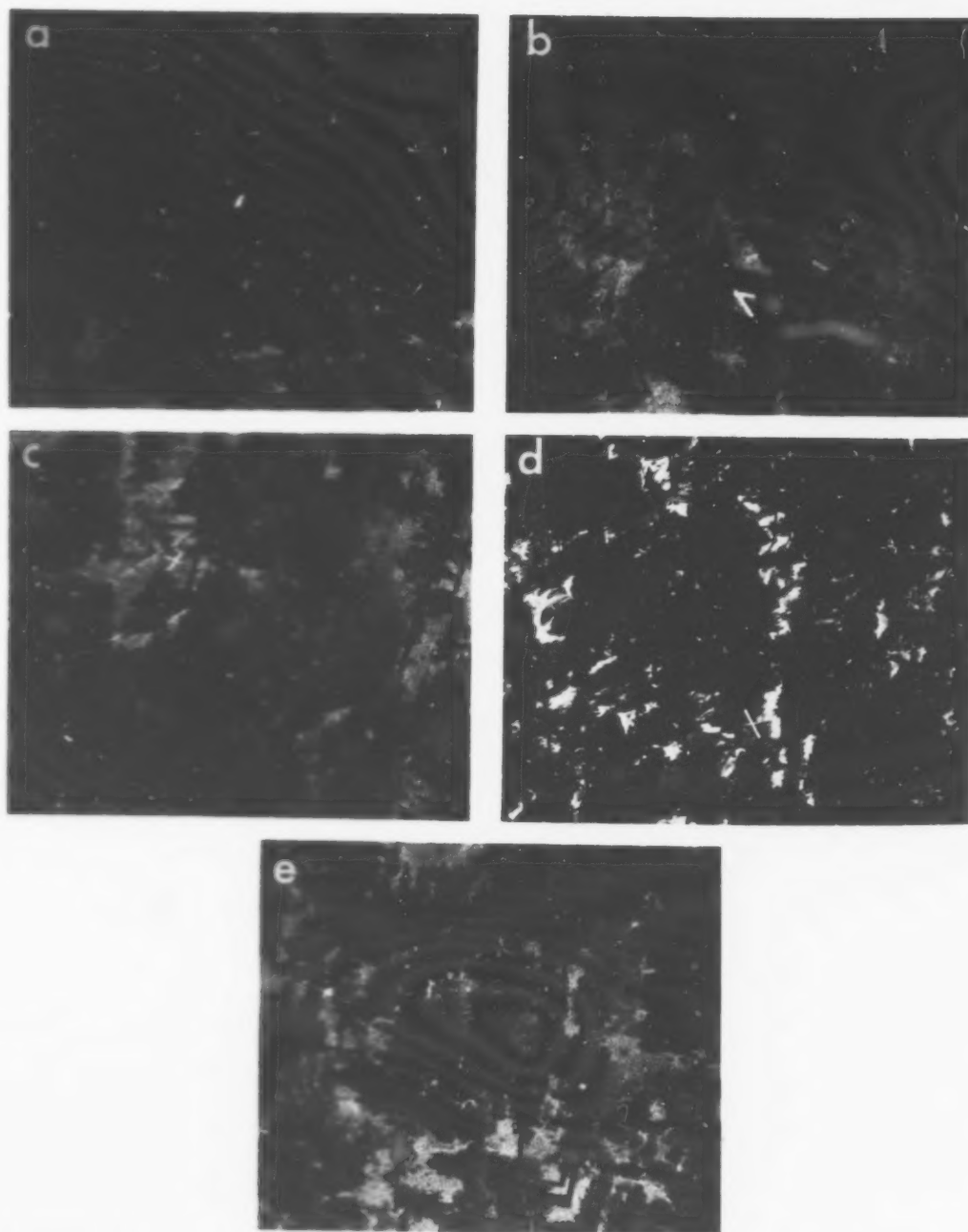


Figure 14. Aerial views of study plots which represent five conifer forest types in the San Bernardino Mountains; from top to bottom:

- a) Ponderosa type, Camp Paivika (left)
- b) Ponderosa-White Fir type, Sky Forest (right)
- c) Ponderosa-Jeffrey pine, Barton Flats (left)
- d) Jeffrey pine-White Fir type, Bluff Lake (right)
- e) Jeffrey pine type, Holcomb Valley

described in terms of the characteristics of the shrub and herb layers (McBride, 1974). The plots occurring in forest types dominated by ponderosa pine have an average shrub cover of 3.8% while those plots occurring in forest types dominated by Jeffrey pine average 26% shrub cover. Arctostaphylos pringlei and Ribes roezlū are typical of the shrub layer in ponderosa pine dominated types. Ceanothus cordulatus, Arctostaphylos patula and Artemisia tridentata are common shrubs in the forest types dominated by Jeffrey pine. The occurrence of herbaceous species in relation to forest type has not been analyzed thus far in our study. The importance value (Curtis, 1951) of each herbaceous species on each of the permanent plots will be calculated. This value will be used as a measure of the relationship between forest type and the occurrence of herbaceous species.

Use of Vegetation Survey Data ---

The descriptive information developed by the vegetation subcommittee has been used by other investigators for the selection of sampling locations, general habitat descriptions, and as a basis for comparison with auxiliary plots. When auxiliary plots were established by the Entomology subcommittee, these plots were surveyed by the vegetation subcommittee using the same procedures used on the permanent plots. This type of survey allows certain comparisons with other data collected on the permanent plots.

SECTION V

TOWARD FORECASTING ALTERNATIVE FUTURE ECOSYSTEM RESPONSES

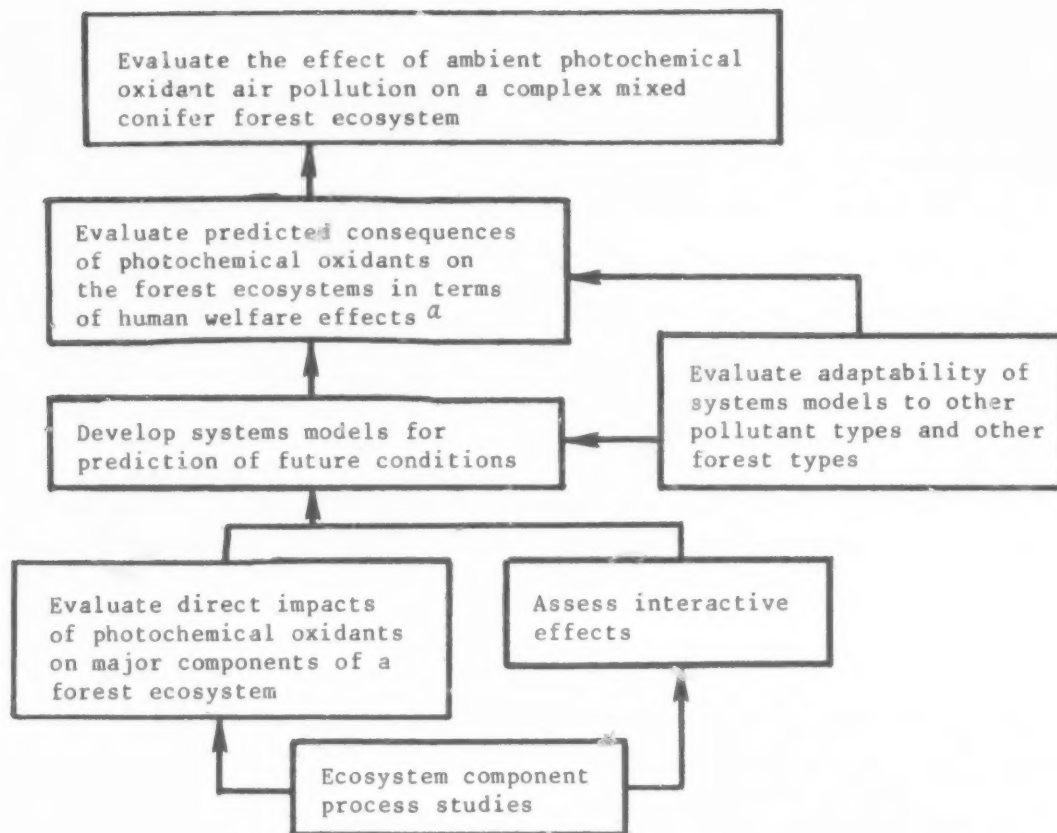
ECOSYSTEM MODELING

Background and Project Objectives

Ecosystems are defined as units which are dependent upon (1) energy and moisture flowing through them, (2) minerals cycling within them, and as a result (3) vegetation reproduces, grows and dies, and supports (4) a diversity of animal life, some of which feeds on the vegetation, and some of which feeds on other animals. In ecosystems, (5) dead organic matter accumulates and (6) decomposer organisms work to break it down so that minerals and space are available for the next generation (Odum 1971). At any given time, some types of organisms are more dominant than other types in the ecosystem processes listed as 3, 4, 5, and 6. Over time, these patterns of dominance go through a gradual change. After a disturbance occurs in an ecosystem, time is set back, and the sequential patterns of dominance begin to take place again. In some cases, the nature of the disturbance may lead to a different sequential pattern of dominant plants and animals than the sequence that prevailed before the disturbance. The subject of ecological succession has received considerable study (Knapp 1974). An alteration of the natural rates of dead organic matter accumulation, and/or its decomposition, could be expected to change the patterns of dominance of vegetation and wildlife communities.

Several investigators are studying this variety of processes in

the laboratory and in the field as the first step in the hierarchy of project objectives (Figure 15, bottom). Such process studies of the components of ecosystems are necessary to determine and quantify direct effects of oxidants as well as the biological effects resulting from simultaneous occurrence of oxidants, drought, insect and plant disease activity. These analyses are necessary in order to assemble our understanding of various processes into a set of quantitative models on an electronic computer. With such models we plan to forecast the various possible alternative futures for the ecosystems in the San Bernardino National Forest (Figure 15, middle). Scientists do not expect to be able to make predictions in an absolute sense, since too many qualifying conditions, such as the future rate of use of the internal combustion engine, and its possible technological modifications, as well as future weather conditions, cannot be predicted with certainty. We can, instead, plan to make forecasts of various possible alternative futures for the forest ecosystems, by postulating sets of alternative, hypothetical qualifying conditions, and seeing how the set of computer simulation models responds to each set of qualifying conditions. For example, one set of possible future conditions might assume twice the annual oxidant dose of 1974 with a three or four year wet-weather pattern of 1 1/2 times the normal rainfall, or alternatively, 1/2 the normal rainfall. We would then determine how the simulated forest system behaves on the computer. There is, of course, no guarantee that real forests will respond as the computer models do, but the other option is merely to use informal, intuitive guesswork on the part of individual specialists, rather than a synthesis of current scientific



^a "...includes, but is not limited to, effects on soils, water, crops, vegetation, man-made materials, animals, wildlife, weather, visibility, and climate, damage to and deterioration of property, and hazards to transportation, as well as effects on economic values and on personal comfort and well-being."

Source: Clean Air Act 1970, Section 302 (h).

Figure 15. Objectives for the study of effects of ambient oxidant pollutants on mixed conifer forest ecosystems.

understanding of the processes which control whatever future forest conditions actually will occur.

Purposes for Building Computer Simulation Models of Ecosystem
Level Response to Photochemical Air Pollutants

The types of ecosystem forecasts to be sought from using the computer models must evaluate likely consequences in terms of "human welfare effects" (Figure 15, top), an expression which can be rather vague from a systems analysis viewpoint, but is defined in section 302(h) of The Clean Air Act, Environmental Protection Agency, 1970: "All language referring to effects on welfare includes, but is not limited to, effects on soils, water, crops, vegetation, man-made materials, animals, wildlife, weather, visibility, and climate, damage to and deterioration of property, and hazards to transportation, as well as effects on economic values and on personal comfort and well-being."

While we expect to find losses in the form of vegetal production decreases and shifts in the balance of species abundance in forest ecosystems under oxidant air pollution stress, probably one of the ultimate questions to put to forest ecosystem simulation models for evaluating consequences in terms of human welfare effects is the question of ecosystem irreversibility. Is there some level of oxidant air pollution, in some time and space definition, at which irreversibility in forest stand succession patterns occurs? Can oxidant air pollutants effect the limits of resilience for terrestrial ecosystems? Particularly, is the detection of such irreversibility possible within

one human lifetime, say 50 years, from 1950, when photochemical air pollution is believed to have begun its chronic trend upward, above natural background levels in the South Coast Air Basin, to the year 2000? In terms of the possible range of air quality conditions from now to the year 2000, one possibility could be a worsening of this air quality in the SBNF by some factor 2,3,4 times that at present. Under such an extreme we might expect changes in the life form of dominant vegetation to occur, as suggested by Woodwell (1970) in his studies on the effects of gamma radiation. The other theoretical extreme, however, is that the present air pollution trend could be reduced by virtually 100 percent at some time in the next 25 years. The irreversibility question asks, if the latter event is induced through political and technological procedures, and the air pollution stress on the forest ecosystems is removed (expectedly at high costs), might the forest ecosystems resume their pre-stress species composition again after a period of readjustment? Can oxidant air pollutants affect the renewability of mixed conifer forest ecosystems?

There are two assumptions whose exploration and evaluation serve as the goal for this work. The first is concerned with constructing an ecosystem-level interpretation for stress induced from oxidant air pollution; the second is an application of analysis and forecasting method.

We think that combinations of non-biological stresses (i.e., increases in ground-level concentration of photochemical oxidants, changes in natural fire frequency distribution, various intensities of meteorological drought) lead to changes in the natural frequency of

periodic biological stresses (insect epidemics, disease epidemics). As a result, sequences of ecologically dominant vegetation will undergo changes which are not likely to reverse naturally, even after the removal of any single non-biological stress.

In order to conduct this study of California mixed conifer forest ecosystems, we feel that a systems analysis and simulation modeling approach will provide participating scientists with a means of:

- a) clarifying their concept definitions and explicitly exposing their assumptions which ordinarily would tend to remain hidden; b) clarification of relationships between system components; c) considering a larger set of interrelated ecological variables than any single investigator is able to observe in the field; d) collating a number of different scientists' data sets; e) comparing similarly structured systems, e.g. from different field plots, having different rates of change; and can provide to government agencies responsible for air quality management and forest resources management, a means of:
- a) forecasting ahead of time the likely responses of ecosystem properties (species composition, yield, stability, resilience) to possible trends in air quality, forest resource harvesting methods, and other environmental stresses;
- b) extension of the range of relevance of a set of field investigations to other sites and other years (see middle of Figure 15); c) in-service education of resource management personnel, through simulation-gaming, of the possible consequences of alternative air quality management and forest management strategies.

Brief Review of Past Research in Support of Assumptions

Evidence Supporting the Ecosystem Stress Interpretation ---

Koenig and Tummala (1972) conceptualize three ecosystem states with regard to pollution. Nonpollution levels exist when pollutants do not cause the ecosystem state to move out of an environmental quality region defined in ecological state space with regard to a set of resource uses. Woodwell (1975) refutes the reality of assimilative capacity of ecosystems, although the nonpollution level concept is also advanced by Smith (1974). A second condition in Koenig and Tummala's (1972) concept is Reversible Pollution. The input rate of pollutants may cause the ecosystem to change beyond the configuration prescribed by the environmental quality region; however, when the stress is removed or "neutralized," by another stress, the system state returns within the initial environmental quality region. A third possible condition is Nonreversible Pollution. Under this condition, pollutant inputs cause ecological states of the ecosystem to move outside of the pre-defined environmental quality regions and remain there even after subsequent reduction of the pollutant stimuli.

Woodwell (1970) presented a general principle of the gross sequence of vegetal life-form elimination from an eastern oak-pine forest with a spatial gradient of increasing exposure to gamma radiation, first trees, then shrubs, followed by herbs, and lastly, low-growing cushion plants. He concluded that this was a chronic effect to be expected from chronic exposures to other chronic environmental stresses. This generalization, when viewed in the context of the aims of this project and the nature of

California mixed conifer forests under oxidant air pollution conditions, causes certain discrepancies to become apparent regarding the perturbation inputs to the system and the stress response of the system.

(1) The conclusion as to what is a chronic exposure and a chronic effect, versus an acute exposure and an acute effect, might be relative to the stress source. Woodwell claims that the pattern of vegetal response was evident after only six month's exposure to gamma radiation. Compared to other environmental perturbations, this immediacy of system response could be categorized as an acute one. (2) If we assume that the input used in the study reported by Woodwell, gamma radiation absorption by vegetation, is not dependent upon the physiologic response of the organisms within the population, then the concept of "exposure," or source "concentration," is sufficient. In contrast, the degree of vegetal absorption of many material air pollutants, such as ozone in the air near the ground, may be dependent upon the time-varying physiologic response of the organism (Makammal, 1965). In these cases, the concept of "exposure" is insufficient for describing the input to the vegetal components of the system. This feedback control in the SBNF under oxidant air pollution would lead one to expect a longer time lag between initiation of pollutant absorption by vegetation and the detectability of effects, compared to the gamma radiation study (Woodwell, 1970). In addition, the latter study used a constant pollutant source compared to the time-varying input of photochemical oxidant air pollutants in this study. One needs to ask how much of a pollutant, with what time periodicity, will cause various degrees of growth

reduction by age class, and between, as well as within, species of a life form group. (3) A longer time lag may allow other additional perturbation inputs to arise in the system. During the study period reported by Woodwell in the gamma radiated forest, no other physical nor biological stresses were reported to have been imposed on the forest ecosystem. This may be because gamma radiation is a more direct mortality agent in the forest, than oxidant air pollutants which, among larger tree size classes, reduce rate of growth and overall vigor enabling other mortality agents to become active. Woodwell makes no reference that the causes of mortality zones observed might have been due to another mortality agent triggered in the course of increased weakening of the various life forms by gamma radiation, so we must assume that his mortality sequence was a straight-forward one of gamma radiation killing vegetation. The claim that results from the gamma radiation study are similar to the responses that can be expected from other forest ecosystems under other types of stresses becomes questionable under these circumstances. In this study of the SBNF, we are looking at possible effects from meteorological drought, plant disease, insect outbreaks, fire, and timber harvesting practices concurrent with the stress induced from oxidant air pollution. Levin (1975) states "...if stability is measured relative to the set of perturbations to which the system is normally exposed (a variable criterion by which different systems are compared with respect to different perturbation sets), then such systems show up as more stable." Underscore and parentheses are Levin's. (4) Woodwell (1970) does not deal with the

evidence that the ranking of inter-species sensitivities to one stress-inducing agent, for example oxidant air pollutants (Miller, 1973a), are often different from the order of sensitivity of the same species to other, different stress agents, such as plant diseases, herbivorous insects, or fire (Wellner, 1970; Kilgore, 1973). (5) In terms of system response to changes in stress imposed, Woodwell's claim for the generality of his conclusions, the nature of the SBNF ecosystems under oxidant air pollution, and the concepts of Koenig and Tummala (1972), one sees that Woodwell's reports (1970, 1975) say nothing about the degree of reversibility of the effect after the stress agent has been removed.

Due to the fact that the professional ecology literature is filled with many natural history, descriptive accounts on the one hand, and with theoretical analyses having questionable application for real world ecosystems on the other, not a great deal of documentary evidence is available on the irreversibility hypothesis although one finds the question raised frequently in the research literature (Koenig and Tummala, 1972; Holling, 1974; Edmonds and Sollins, 1974). Bryson and Wendland (1970) claim that the arid lands of India are a result of defoliation and elimination of vegetation which induces local climatic changes inconducive to the re-establishment of the original vegetation. Chorney et al. (1975) provide evidence for a similar positive feedback for the Sahara. Glendening (1952) has shown that a defoliation stress due to grazing intensity which then enables tree establishment will not allow the ecosystem to revert back to its prior condition even after

removal of the stress. Holling (1974) discusses evidence of aquatic ecosystems failing to rejuvenate when stresses are removed. Habeck and Mutch (1973) discuss the likelihood of forest fuel accumulations being so great now, after a lowering of the natural fire frequency through fire protection programs, that should those ecosystems now be subjected to an uncontrolled fire, the heat intensity would probably be far greater than that to which the systems are evolutionarily adapted. La Chapelle (1967) reported on management attempts to reverse the otherwise irreversible changes in Austrian sub-alpine timberline forest equilibrium which resulted from previous logging and grazing activity which activated a high frequency of snow avalanche perturbations in the forest ecosystems.

Evidence Supporting the Usefulness and Necessity of Computer Modeling of Ecological Systems ---

Three stages of usefulness in applying systems modeling methods to environmental research are identified by Innis (1973). "Conceptual utility" is derived from the integrated frame of reference which an explicit model, or set of interconnected submodels, provides. "Developmental utility" is the usefulness of the ideas which the modeler and presumably his field biologists acquire when assembling the various functional hypotheses that comprise a simulation model. A large amount of the published literature on ecological systems simulation is descriptive methodology in the sense that the article describes details of how parts of the system model were constructed, but not what was done with the model after it was constructed. Experimental reports explain-

ing what discoveries were made at the ecosystem level as a result of using the simulator, and accompanied by displays of the results of the simulation experiments as evidence, are rare. The National Academy of Science (1974) and the National Science Foundation (1972) have provided some evidence of the conceptual and developmental usefulness of computer simulation modeling in ecosystem research. For an interesting discussion of the value for non-scientists, as well as scientists, of explicitly exposing assumptions used to construct a simulator, one can refer to the discussion by Yorke following the paper by Boling and Van Sickle (1975). Wiegert (1975) presents examples of the clarification of relationships between system components which occurs when one is working with a simulator. The ability to consider a larger set of ecological variables than a single investigator is able to observe, and the collation of various specialists' data sets, is true almost by definition without the need for evidence, although a critical study of, for example, the article by Van Dyne (1972), a team interdisciplinary approach, compared to the papers in Fries (1974), a set of very disciplinary approaches, reveals the difference clearly.

The third stage of usefulness identified by Innis (1973) is "Output Utility." This is the set of information from the computer model performance which is in some sense useful by other people who were not directly involved in the model development. Innis attributes the relative sparsity of published evidence at present for output usefulness of ecological simulators as resulting from their dependence on more uncertainties than comparable quantitative relations in the physical sciences. Biswas (1975) also presents some reasons and remedies for

system simulators not being used more frequently for environmental management decision-making. An example of one type of output utility, forecasting of ecosystem responses to trends in environmental stresses, is found in Giese et al. (1975). This purpose is central to the objectives of the Environmental Protection Agency in the present study (Figure 15).

Another output utility, extending the range of relevance of investigations to other different locations and/or for other years aside from those during which the study is performed, is discussed by Goodall (1972). This purpose is also shown in the hierarchy of project objectives in Figure 15. It may be a crucial one. To the extent that our system simulators developed for the SBNF can be applied to coniferous forests elsewhere in the western states for making comparative projections on a geographic scale we may be able to avoid having this study treated by others as simply an isolated case study for one particular location.

The usefulness of simulation-gaming for resource management personnel is treated by Holling and Chambers, 1973, and Biswas, 1975.

Subsystems of the Forest Ecosystem and Their Investigators

As a result of the complexity in ecosystems, a division of labor among research ecologists is necessary. It is all too easy, however, to lose sight of the whole system as an operating unit (Figure 16). In the following sections of this report, each of the project's ten process investigators discuss subsystems of the whole ecosystem. In Figure 16, only the labels for these subsystems, and their coupling with other

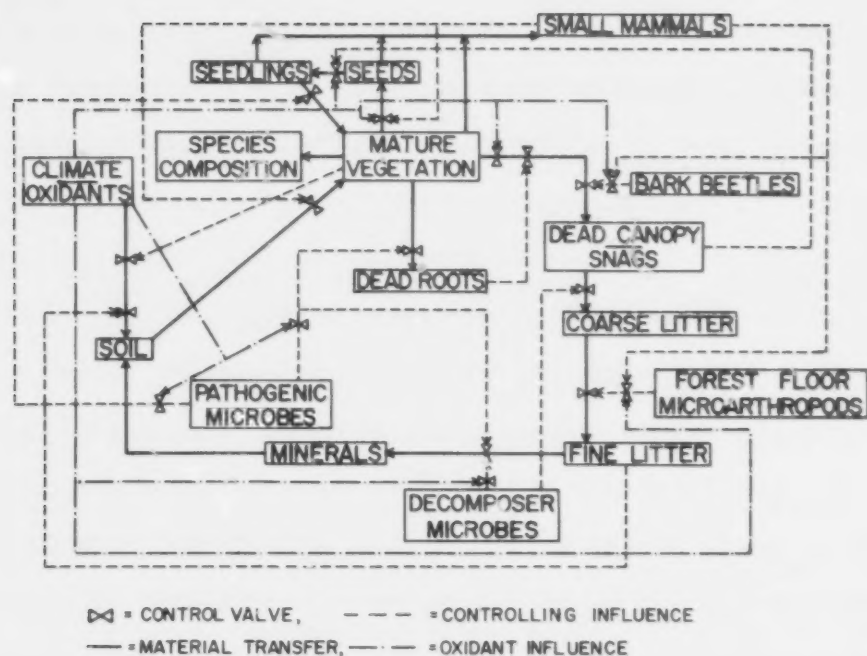


Figure 16. Subsystems being investigated by various project investigators within the forest ecosystem.

subsystems, are represented, not the details within them. Any two or three boxes, connected by arrows, represent one of the investigators' subsystems. A solid-line arrow represents a transfer of material from one sub-subsystem to another, with the exception of "species composition", where only a change in a characteristic property is implied. The dashed-line arrows and "bow-tie" symbols indicate a control is exerted on the rate of flow represented by the solid line. The dash-dot-dash arrows represent the same information as the dashed-line arrows except that the former refer to oxidant air pollutants' impact directly. It bears emphasizing that the detailed interactions between observable quantities in the ecosystem are hidden from view in this

diagram. Some of these details will be revealed in each of the subsequent sections of this report.

To an extent, the sequence which is used in this report to discuss the various subsystems under investigation is arbitrary; there is no natural starting point when one begins to draw a circle. The logical sequence we have chosen, however, is to present information about initial states of the structure of these forest ecosystems, with regard to climate, soils, and vegetation in Section IV. With regard to forecasting possible future states of these ecosystems, the third subsection of Section V, presents information on the environmental variables of major interest to this project in "driving" the ecosystems toward their future conditions, photochemical air pollutant concentrations, and their meteorological dispersion processes. The next set of information deals with ecosystem processes, namely vegetational growth, accumulation of dead organic matter in the forest, and processes controlling the rate of decomposition of this material. The majority of the public perceive only the wildlife and vegetation components of this complex system when they visit the forest. As with any complex system, however, there exist many other absolutely essential components and processes which are equally important in the dynamic behavior of the system, but are not readily visible to the casual observer. Apparent visibility is no guide to importance within the system. The last portion of Section V deals with system response and the degree to which kinds of forest vegetation will be able to perpetuate their existence in the presence of oxidant air pollutant stresses.

For the purpose of designing computer simulation models to mimic

each of the subsystems, the project investigators are involved in a sequence of stages for planning, development and application of systems models, as shown in Figure 17.

Methods of the Modeling Design and Development Process

After the field monitoring design was established, the investigators made initial explorations on conceptual models describing the ecosystems (Taylor, 1974). In January 1975, a systems ecologist was added to the project to organize and coordinate the systems modeling effort.

Model construction is planned to evolve into a modified form of "model-oriented, computer-assisted conferencing system" as described by Kupperman, Wilcox, and Smith (1975). Two of the principal investigators are located at the University of California at Riverside, and nine are located at the University of California at Berkeley. A portable computer terminal is carried around for on-line access to a computer center time-sharing system during modeling sessions.

With respect to the stages of modeling (Figure 17), the definition of forecasting goals for the overriding project problem is a critical starting point (Giles, 1972). Since two of the objectives (Figure 15) are to "evaluate adaptability of systems models to other pollutant types and other forest types," and to forecast possible consequences of photochemical oxidants on the forest ecosystems in terms of human welfare effects, we must see that the simulators which we develop are not too exclusively customized for giving forecasts on conditions of unique interest in the San Bernardino National Forest, compared to other

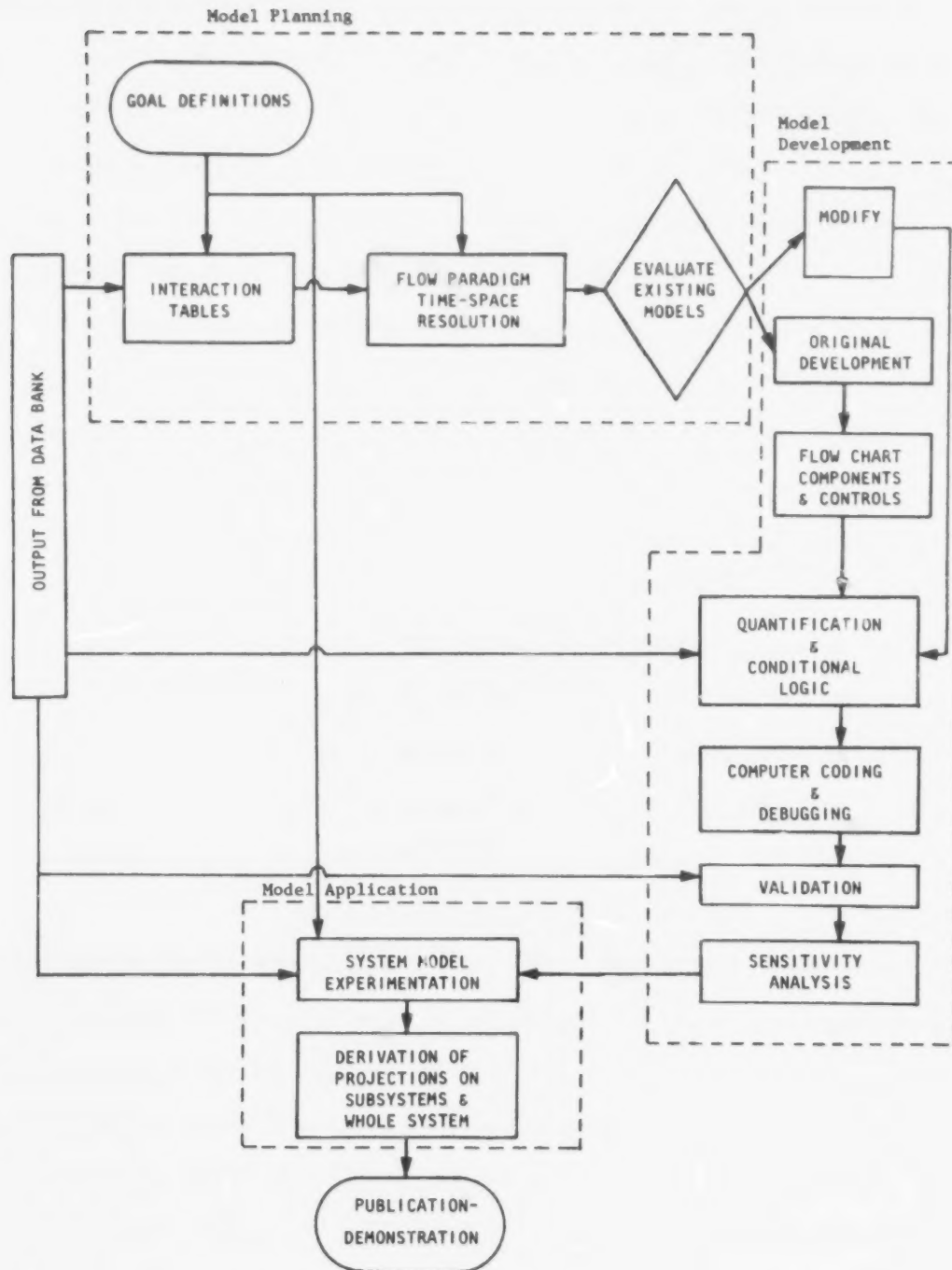


Figure 17. The system simulation modeling process.

more remote forests. Otherwise, the adaptability of such models is bound to be very low by original design. Table 5 indicates how various use-policies for different forests are likely to affect the forest conditions for which we might want forecasts under possible future air quality environments.

One of the major problems which this research group continually needs to address is this: for what kinds of questions will the set of system simulation models be expected to provide forecasts regarding possible alternative future conditions of the forest so that the ecosystem irreversibility question discussed earlier can be examined? We might then state an intermediate forecasting goal as follows: What might be the effect of various changes in photochemical oxidant air pollutant trends over the next 50 to 100 years, as seen in (1) number of dead trees per hectare, (2) the rate of change in tree species composition for ponderosa and Jeffrey pine, and (3) the vegetal life form (trees, shrubs, grasses) and species which are likely to assume an ecologically dominant role in various plant and animal communities within the California mixed conifer forest type?

The work of Kickert et al. (1975) provides a useful inventory of questions needing to be answered, by analysis of computer model behavior, as evaluated by scientists and land managers for that aspect of the problem that involves organic matter accumulation and its periodic decomposition by fire events, a set of stresses which can occur concurrently with oxidant stress.

The next step (Figure 17) is the construction of interaction tables that show merely which variables are involved in various subsystems and

TABLE 5. POTENTIAL COUPLINGS BETWEEN STRESSED ECOSYSTEM RESPONSES AND SOCIO-POLITICO-ECONOMIC SYSTEMS UNDER VARIOUS FOREST LAND-USE POLICIES.

<u>ECOSYSTEM STRESSES</u>	<u>LAND-USE</u>	<u>ECOSYSTEM RESPONSE</u>	<u>SOCIO-POLITICO-ECONOMIC IMPACT (POSSIBILITIES)</u>
OXIDANTS	WILDERNESS FORESTS i.e. WILDERNESS AREAS USFS NATIONAL PARKS NPS RESIDENTIAL- RECREATIONAL FORESTS MULTIPLE-USE FORESTS	VEGETAL AND WILDLIFE SPECIES COMPOSITION CHANGES	-CONTRADICTION OF LEGISLATED POLICY FOR LAND MANAGEMENT
DROUGHT			
FIRE			-DEGRADATION OF RECREATIONAL EXPERIENCE
INSECT EPIDEMIC			
DISEASE EPIDEMIC		DRY FUEL ACCUMULATION	-FUEL REDUCTION COSTS (PRIVATE-OWNER)
		TREE CANOPY DECREASE	-FIRE CONTROL COSTS -FLOOD CONTROL COSTS REAL ESTATE TAX REAL ESTATE MARKET VALUE
		GAME ANIMALS	-HUNTING
		TIMBER PRODUCTION AND CUT	-ALLOWABLE CUT LUMBER COST
		FORAGE PRODUCTION AND QUALITY	-GRAZING PERMITS

whether the interaction between any two variables is positive or negative, an accelerating effect or decelerating effect. A previous Task D Report (Taylor, 1974) showing various types of interaction diagrams has been an aid.

The next stage (Figure 17) involves selecting the appropriate paradigm for the substance which is conceived as flowing through the various subsystems. A discussion of various types of paradigms is found in Noy-Meir (1973). Possible flows may be energy, water, various mineral nutrients, biomass, population densities, number of taxonomic species, area occupied per biotic unit, or other possibilities.

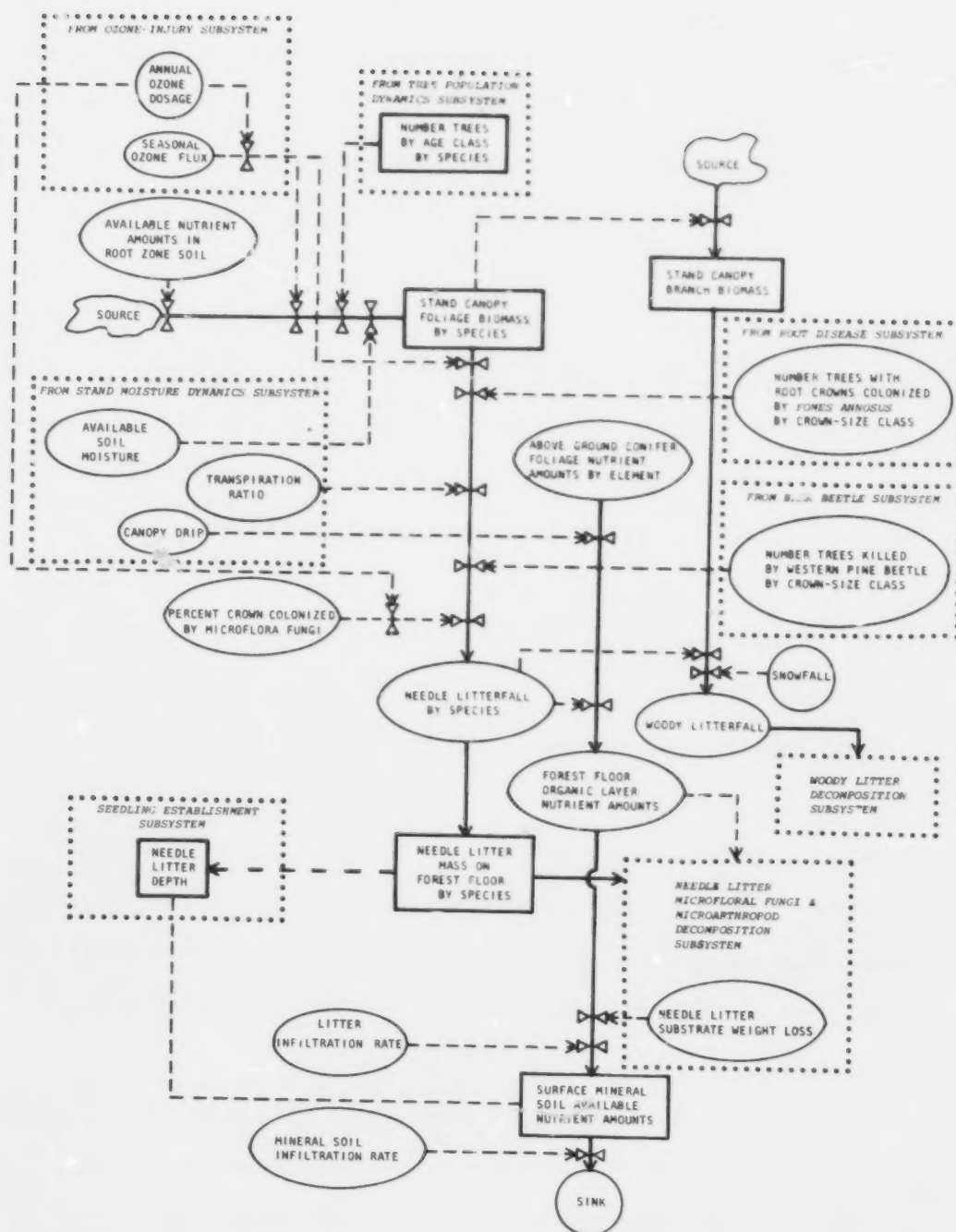
Ecosystems can be defined at various spatial scales and for various time scales. In this project, ecosystem simulators are planned for the forest stand-community level. The stand-community ecosystem model may simulate a time period of perhaps 50 years to 100 years at annual intervals.

Review and evaluation of published simulation models (Figure 17) for ecological systems is being done in order to build upon the work of others wherever possible. For this purpose, continuous use is made of the University of California Center for Information Services for literature searches in the Cataloging and Indexing System (CAIN) for agriculture, and also Biological Abstracts and Bio-Research Index. Some existing models which we are modifying for subsystem simulation are indicated below. Flow charts, as graphic representations of subsystem model structures, have been defined, and will subsequently be translated into computer code, for the following subsystems: (1) oxidant flux-stand canopy response, drawing upon ideas of Mukammal (1965),

and Reed and Waring (1974); (2) stand-level heat energy flow; (3) forest stand moisture budget, with temporal modifications to the stand water flow simulator described by Sollins et al. (1974); (4) forest stand growth, using a simulator developed by Dr. Kenneth Reed (personal communication, 1975); (5) stand level Fomes annosus root pathogen infection, spread, mortality response; (6) western pine bark beetle population dynamics-stand mortality response, using some of the work of Stage (1973); (7) stand level needle litter and woody litter production; (8) stand needle litter decomposition by micro-floral fungi with micro-arthropod population dynamics; (9) woody litter decomposition; (10) cone and seed production; (11) small mammal population dynamics and seed predation in a forest stand, drawing on Patton (1975); (12) damping-off fungi dynamics in conifer seedling establishment; (13) conifer tree population dynamics.

An example of one of the subsystem flow charts is given in Figure 18. The same graphic symbolism of Figure 16 applies in Figure 18. Functional interactions hypothesized to exist with other donating and receiving subsystem models can be seen. We are now moving into that stage of quantifying relations indicated in the flow chart models and using these to construct the computer programs for the subsystem simulators.

Documentation is being kept on the modeling stages as each of the subsystem investigators proceeds through the sequence shown in Figure 17. Such documentation is in line with Mar's suggestion (1974) to include, for each simulation model: (1) identification of personnel involved in construction, (2) documentation of model framework and



Note. Nutrients are N, P, K, Ca, Mg in Kg/ha.

Figure 18. Needle litter and woody litter production subsystem.

theory, (3) flow charts, (4) description of methods to reduce data to construct models, (5) listing of system variables and definitions, (6) literal description of computer programs for models, (7) computer program listing, (8) programmer manual, (9) operator's manual, (10) construction, operation and maintenance data, (11) history of review by peers, and (12) record of users and outcome.

As Figure 17 indicates, the ecological systems modeling process will be partially dependent upon the Data Management System being designed by Barbieri.

THE DATA MANAGEMENT SYSTEM

In any realistic attempt to study a particular environment it is apparent that large amounts of diverse and highly structured data will have to be collected and efficiently stored. The data are, in general, dependent on the intrinsic properties of the process being measured and on the sampling technique employed. In order to handle the large volume of field data, a computer processing procedure seems advisable.

In this study, the types of field data being collected can be subdivided into six broad study classes: meteorological-pollutant dose information, vegetation information, arthropod information, soils information, pathogen information, and wildlife information. Each of these broad classes of information can be further subdivided into the actual type of data being collected. For example, vegetation information is composed of six different data types. Thus, the hierarchical structure of the data is a mimic of the hierarchical biological structure of the SBNF.

To process the volume of extremely varied data for the SBNF study, an efficient data management system has been designed at Lawrence Livermore Laboratory. The purpose of the data management system is to efficiently collect, store and process data which can then be used in various types of ecosystem models. The data management system designed for this study is divided into three general sections: data capture, data banking, and data manipulation.

Data Capture

Data capture is defined to be the collection of techniques which are used to convert field data into a format which is suitable for storage into a computer. Because of the variability in the types of field data being collected, no one data capture scheme will satisfy all of the field researchers. The data capture system should, therefore, be general enough to accept data with a quasi-arbitrary structure in which the field collected data itself becomes the basis for entry into the computer system. For the SBNF project, a fieldfree format input was developed in which the field data are not required to appear in specified columns on a data sheet. By allowing the field researcher to design his own data sheets, it is hoped that the amount of error in handling data will be minimized.

Computer systems have a tendency to fail catastrophically if the field data are not recorded in a precise and consistent manner. To counteract this tendency, the data capture system designed for the SBNF study notes inconsistencies and then ignores the inconsistency -- such data are not processed. Therefore, instead of rejecting whole data

sets because of an error in the data set, the data capture system records the error and then processes the remaining acceptable data.

The data capture system is itself divided into three types of computer routines: The executive and library routines, the operational routines, and the decoding routines. The executive routines contain all of the general logic for determining the type of data being entered and also contains a library of all names and mnemonics used by any of the operational routines. The decoding routines are responsible for decoding and classifying the actual data into integers, floating point numbers, alphabetic character(s) and/or special symbols. The operational routines determine whether the data is of an acceptable format and stores the acceptable data into given locations for future use. A schematic diagram for the arthropod data capture system is given in Figure 19. Presently the data capture system is capable of accepting twenty different field data types.

Each operational subroutine will have summarization and statistical analysis capability which will analyze the incoming field data. The summarization and statistical analysis performed by these packages are determined by the requirements of the user. At present there are eight summation routines coded. Once the data are in an acceptable form, they will be stored in a data bank.

The Data Bank

The data banking system which will be used is a system designed for Lawrence Livermore Laboratory called Master Control (Hampel and Ramus, 1975). Master Control is a computer program designed to unify

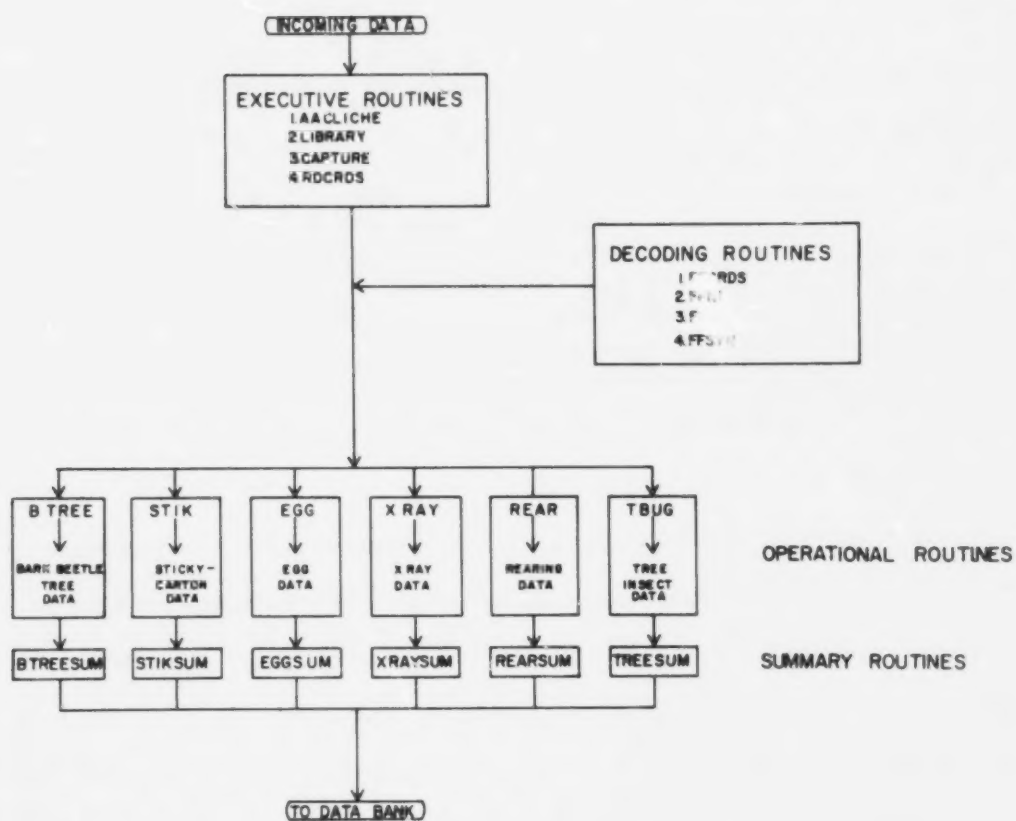


Figure 19. The arthropod data capture system.

storage, manipulate, reorganize, retrieve, and display data from dissimilar data bases. It is open end and user oriented. Some of the characteristics of Master Control are packed memory allocation, hierarchical ordering using pointers for random access, a telegram-like command language, and options to interrogate and manipulate data bases in both batch modes or time-share modes. Master Control allows progressive adaptation of data bases to contemporary needs (Figure 20).

Each of the six main classes of field data (vegetation, arthropods, etc.) will initially have its own data bank created by Master Control. In each of these data banks, the processed field data received from the data capture routines will be stored. Using the general command language of Master Control, new data banks can be constructed which will reflect the needs of the user (Figure 21). The command language consists of ten general operations. The operations are (1) define,

BASIC DESIGN PHILOSOPHY OF MASTER CONTROL

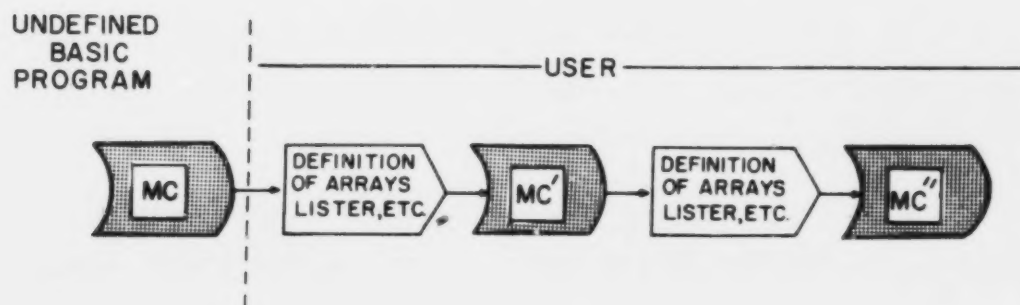


Figure 20. Basic design philosophy of 'Master Control'.

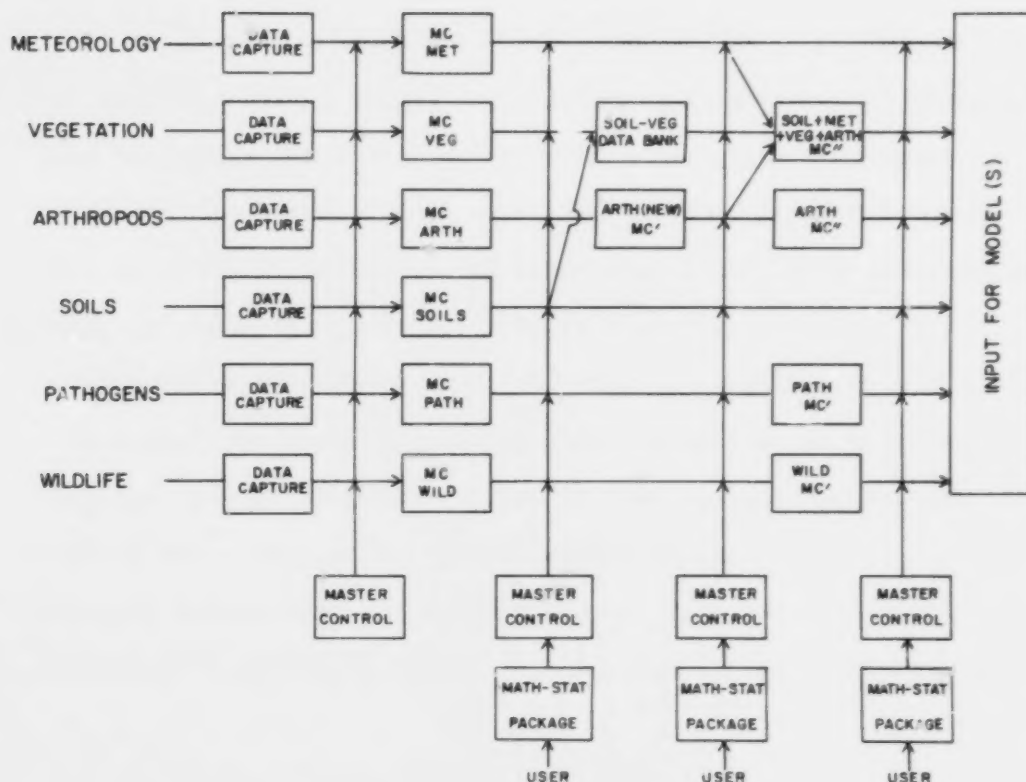


Figure 21. The San Bernardino Data Management System.

(2) initialization, (3) generation, (4) construction, (5) file transfer, (6) alter, (7) edit, (8) search, (9) numerical operations, and (10) macro-operations.

At present Master Control exists on the Lawrence Livermore Laboratory CDC-7600 and CDC-6600 and is written in the CHAP language -- an internal version of FORTRAN-IV. Master Control, however, is currently being modified so that it will be compatible with other computer systems. Work on applying Master Control to the SBNF study

began in April 1975.

In order to use the data banking system effectively it will be necessary to provide the user (either the modeler(s) or subsystem investigators) with a library of numerical, statistical, and graphical techniques.

Data Manipulation

The data manipulation facility of this data management system will contain a library of operational programs which can be used to analyze parts of the data in any given data bank. This facility will reflect the desires indicated by the modeling activity, and together with the commands available in Master Control, will provide the modeling activity with a method of obtaining data for input into various model development activities.

There exist a variety of approaches which have been used to design ecological system models (Jeffers, 1973; Mar, 1974). As a consequence of this diverse condition in the state-of-the-art, and also since field data for this project are being collected on four different classes of observations: nominal, ordinal, interval, and ratio scale, the specific data manipulation procedures have not been defined yet. In general, they will comprise three separate categories of computer programs as identified by Bridges (1974): (1) graphic display procedures to visually examine graphic plots, spatial maps, response surfaces, and tabularization of observations from field sites and computer model behavior, (2) statistical procedures for use in model design and subsequent model evaluation against the actual landscape ecosystems, and

(3) ecological subject data procedures which transcend conventional statistical methods and provide computer analysis capability for climate analysis, population analysis, biological community analysis, and calculation of ecosystem indices such as species diversity.

TRENDS OF PHOTOCHEMICAL AIR POLLUTANT CONCENTRATIONS DURING GROWING SEASONS

Oxidant Trends in Downtown San Bernardino and at a Nearby Mountain, Forest Station

The National Primary and Secondary Air Quality Standards for Photochemical Oxidants (California Air Resources Board, 1974), Appendix A, provide the basis for evaluating the trends of concentrations in the area under study. Data are available back to 1963 from the downtown San Bernardino station operated by the County Air Pollution Control District (APCD). The colorimetric potassium iodide method was used to measure total oxidants. A recent revision (California Air Resources Board, DeMore Committee, 1974) for calibration of ozone sensing instruments suggests that an interim correction of all ozone concentration data could be made with a multiplication by 0.80. The former primary standard calibration procedure, using buffered potassium iodide, was found to be 20% higher than ultraviolet photometry which has now been accepted as a valid primary (transfer) standard in California. Beginning in 1968, continuous total oxidant measurements were obtained at Rim Forest/Sky Forest by the Forest Service, Pacific Southwest Forest and Range Experiment Station, from June through September annually. The Mast ozone analyzer employed was calibrated according to the

method of the California Air Resources Board. A positive correction factor of 1.22 was employed to adjust for decreased pressure at the mountain station compared to the calibration site at Riverside.

Another useful way of identifying the trends in air pollution doses is to compare the number of days or total hours each year when concentrations exceed some threshold higher than the Federal Standard, $160 \mu\text{g}/\text{m}^3$. At the selected threshold, human health and welfare is imperiled especially because the daily peak oxidant concentration can reach up to $1176 \mu\text{g}/\text{m}^3$ (0.60 ppm) on these days. Local communities and both State and Federal agencies have adopted different threshold values to signify adverse effects. The State of California employs several descriptive thresholds, one being $392 \mu\text{g}/\text{m}^3$ (0.20 ppm), to identify the frequency of air pollution episodes or periods of sustained high concentrations of atmospheric pollutants.

Data from the mountain station at Rim Forest/Sky Forest were compared with published data from the San Bernardino County APCD in terms of the number of hours during which total oxidant concentration exceeded $392 \mu\text{g}/\text{m}^3$ (0.20 ppm) during July, August, and September from 1968 to 1974, when both stations operated. From 1963 to 1967, data are available only from the San Bernardino APCD station, Air Resources Board (1973). A large part of the year-to-year differences at the same station and between stations can be attributed to differences in synoptic and mesoscale meteorological patterns. For example, the differences in 1972, 1973, and 1974, at Rim Forest/Sky Forest (Figure 22) are associated with 6, 16, and 46 days respectively, when a persistent 500 mb high pressure system occurred over the

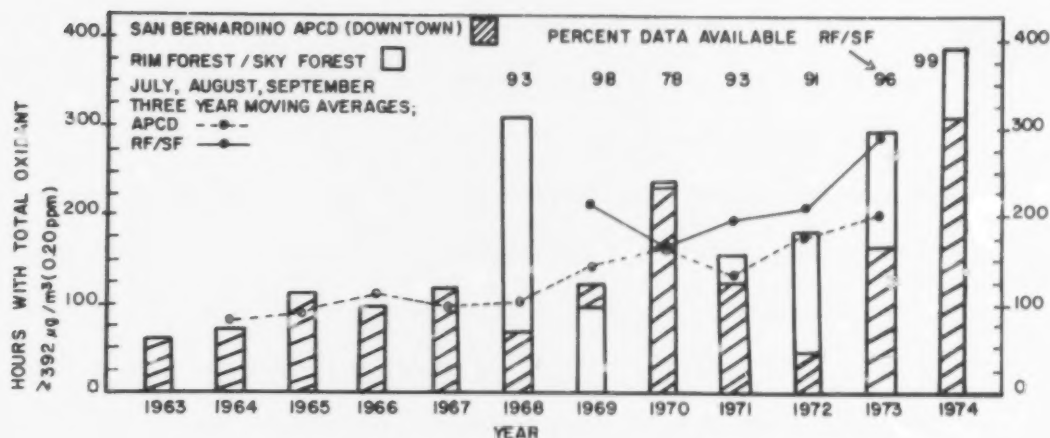


Figure 22. Number of hours of total oxidant, July through September, greater than or equal to $392 \mu\text{g}/\text{m}^3$ (0.20 ppm) at the downtown San Bernardino County Air Pollution Control District Station, 1963-1974, and Rim Forest/Sky Forest, 1968-1974. (For absolute values, oxidant concentrations might be multiplied by 0.8 to comply with a new, tentative calibration procedure.)

southwest, particularly southern California. The difference between stations in the same year is probably influenced most by inversion height. Lower inversion heights would partially restrain transport upslope to shorter periods daily. Higher inversions would have the opposite effect and in addition allow a greater air volume below to dilute oxidants. The index for comparison chosen in Figure 22, i.e., hours with total oxidant concentration $\geq 392 \mu\text{g}/\text{m}^3$ should be largely determined by inversion height. The three-year moving averages for each station tend to remove some of the variation due to higher frequency fluctuations. In terms of hours with total oxidant concentration

$\geq 392 \mu\text{g}/\text{m}^3$, the moving average between 1970 and 1973 at Sky Forest/Rim Forest has increased from 175 to 290 hours. This trend is the reverse of that in upwind, urban Los Angeles County where increased emissions of NO (nitric oxide in fresh auto exhaust) tends to shift the chemical equilibrium to the left towards the ozone precursors in the chemical reaction which produces ozone.

The most recent data analyzed suggest that oxidant will either increase annually or oscillate around the mean of present high levels in the foreseeable future at these distant locations unless dramatic improvements are made in control strategies (Corn et al., 1975; Blumenthal et al., 1974).

A second method of documenting trends of oxidant levels during the 1968 to 1974 period at Rim Forest/Sky Forest expresses the accumulated dose ($\mu\text{g}/\text{m}^3\text{-hr}$) and number of hours of dose $\geq 157 \mu\text{g}/\text{m}^3$ (0.08 ppm), the Federal Standard, Appendix A, for June through September (Figure 23). This period represents the main part of the growing season; however, doses during the remaining months of the year are also being documented in present and proposed work. These doses exclude the background concentration of less than $59 \mu\text{g}/\text{m}^3$ (0.03 ppm), as reported by Gloria et al. (1974). The percent of valid data recovered is also indicated. The absence of some data, up to as much as 17.8 percent in 1970, but averaging 8.3 percent during the seven years, presents a margin of error that cannot presently be adjusted with any certainty. Future analysis of past meteorological data may permit some adjustments to be made. The percent of the total possible hours for which data could be obtained during the June through September period is also indicated. The

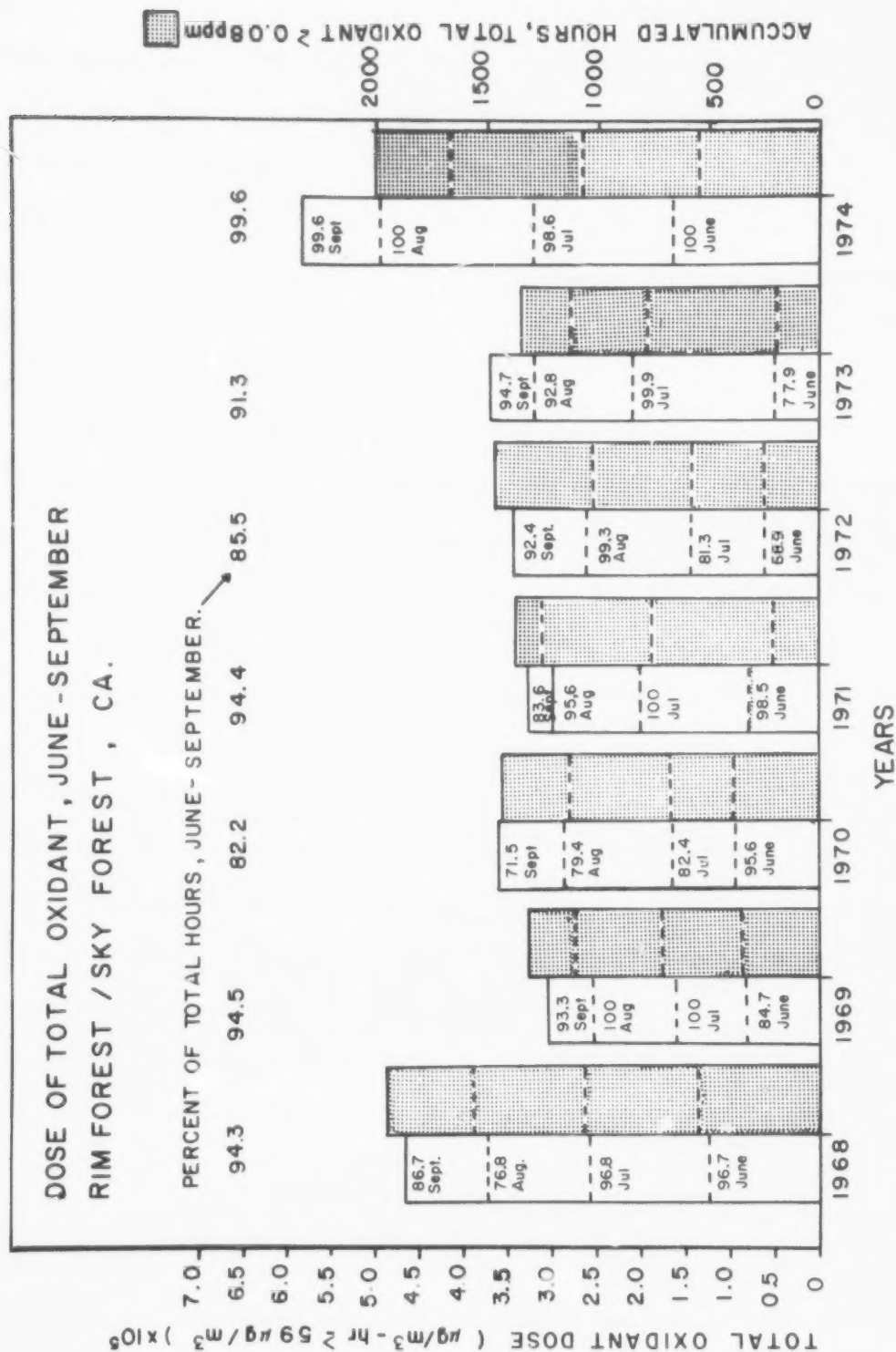


Figure 23. Monthly summation, June through September, 1968-74, of total oxidant dose and total number of hours at a dose greater than, or equal to, $157 \mu\text{g}/\text{m}^3$ (0.08 ppm), at Rim Forest/Sky Forest. (For absolute values, oxidant concentrations and doses might be multiplied by 0.8 to comply with a new, tentative calibration procedure.)

number of hours with total oxidant concentration $\geq 157 \mu\text{g}/\text{m}^3$ (0.08 ppm) was never less than 1300 hours per year during the seven year period. The present level of compliance with Federal Air Quality Standards can be described as a ludicrous situation.

The dose data have been used to estimate dose-injury relationships for ponderosa pine needles (Figure 32) and are being stratified in various ways to test for possible correlations with radial (ring) growth of ponderosa pine (Figure 43).

Comparative Daily Maximum Hourly Averages for Ozone, Total Oxidant, PAN, and NO_2 at Sky Forest, August 1974

The daily concentrations of ozone and total oxidant for August 1974 closely mimic one another (Figure 24). The data from the DASIBI ultra-violet spectrophotometer, which measures ozone specifically, were always lower than the Mast KI instrument, which responds to other oxidants, except for one day, August 8. It is important to observe that ozone is a good surrogate for the total oxidant measurement, and in addition it is the most important pollutant causing injury to conifers. Because August is usually one of the more severe months for pollution, this record probably displays one of the highest frequencies of air pollution episodes to be expected in the mountain area. PAN concentrations were sufficient to cause injury to common herbaceous plants frequently used in laboratory studies, but PAN symptoms were not distinguished from ozone symptoms on nearby herb layer plant species. Nitrogen dioxide remained at low concentrations compared to the other oxidants.

Comparative Hourly Concentrations of Total Oxidant, Nitrogen Dioxide (NO_2) and Peroxyacetyl Nitrate (PAN)

A comparison of total oxidant at Sky Forest, Big Bear Station, and Barton Flats, with winds at Sky Forest and Big Bear Ranger Station during two days in October 1973 (Figure 25), shows that total oxidants may peak out later at more distant stations (October 18) or nearly simultaneously (October 19). The stronger winds on the 19th may have caused

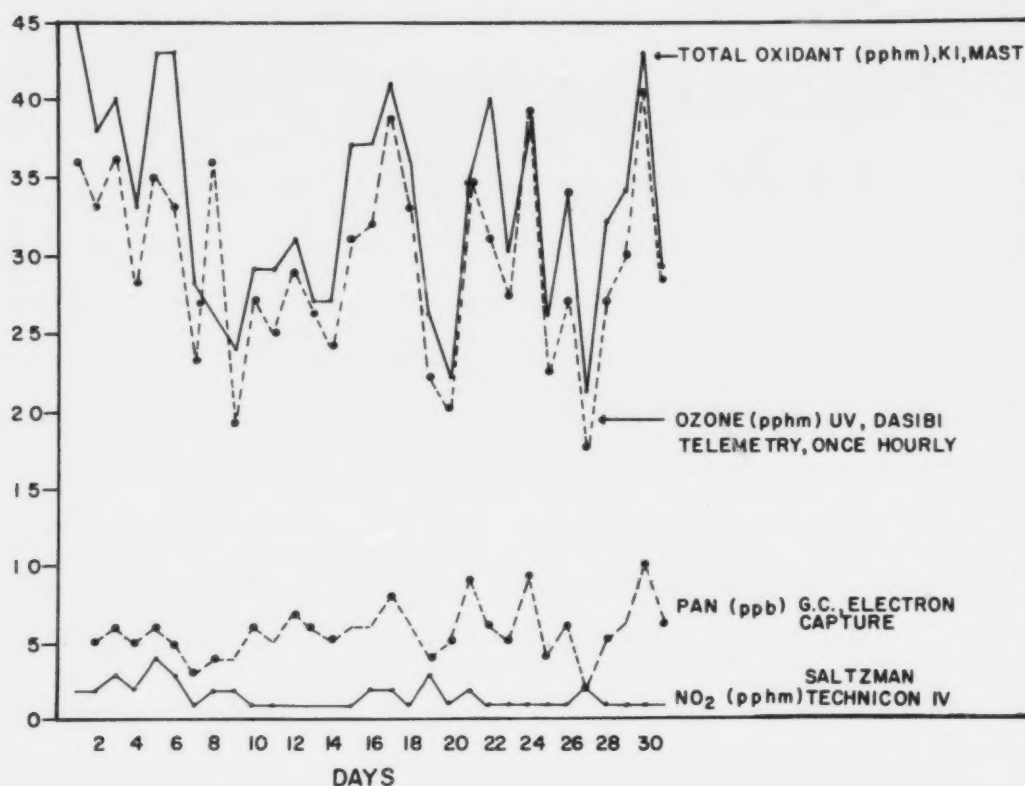


Figure 24. Comparative daily maximum hourly averages for ozone, total oxidant, PAN and NO₂ at Sky Forest, August 1974. (For absolute values, oxidant concentrations might be multiplied by 0.8 to comply with a new, tentative calibration procedure.)

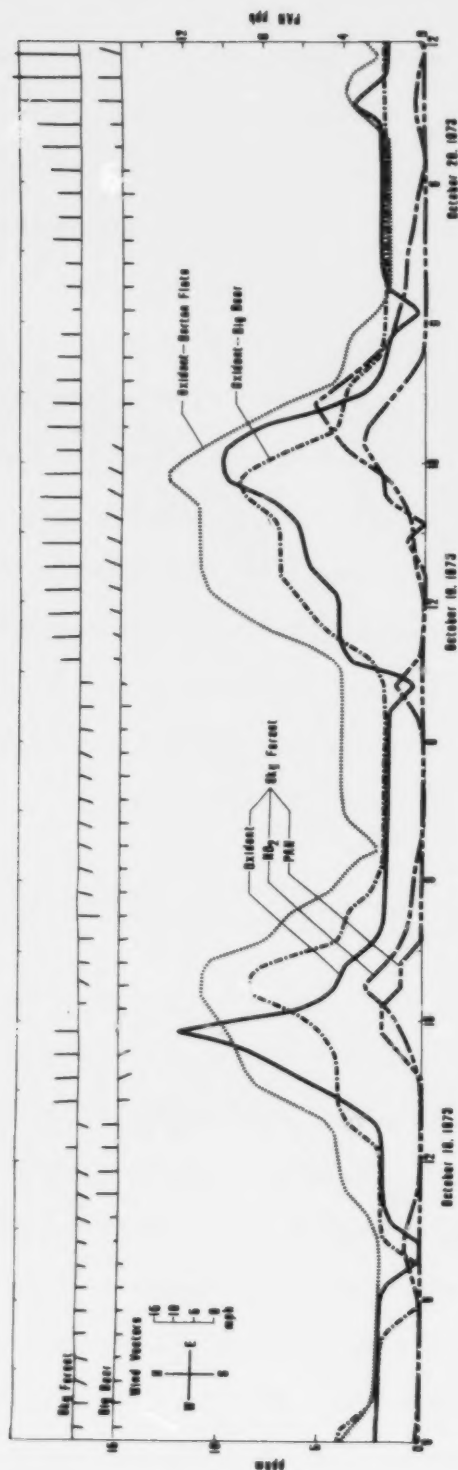


Figure 25. Comparative hourly concentrations of total oxidant, PAN, and NO_2 at Sky Forest, November 18, 19, 1973, and total oxidants at Big Bear Ranger Station and Barton Flats. (For absolute values, oxidant concentrations and doses might be multiplied by 0.8 to comply with a new, tentative calibration procedure.)

the more uniform peaking time. At Sky Forest, PAN peaks a littler later than total oxidant. Nitrogen dioxide has a very small peak around 0800 hr and a larger one at 2000 to 2100 hr PST.

The interaction of time of day when oxidants reach adverse levels with the prevailing meteorological conditions at that time undoubtedly influences plant susceptibility. Studies are in progress with cooperators at the USDA, Forest Service Fire Laboratory at Riverside, California, to collect the meteorological data necessary to generate air temperature, humidity, and wind fields with computer models. Three telemetering stations located at Camp Paivika, Sky Forest, and Barton Flats continuously measure winds, air temperature, humidity, net radiation, and ozone at hourly intervals during the growing season. The first objective is to understand the relationship of terrain to surface flow in order to interpret pollutant dispersion.

Definition of the West to East Gradient of Surface Total Oxidant Concentrations in the San Bernardino Mountains, 1974

Seven ground stations were maintained from June through October, 1974, along a west to east transect. These stations can be located by intersection on the scales superimposed above the topographic projection of the San Bernardino Mountains (Figure 26). The cumulative monthly doses which are presented in Figure 26 do not include data from every hour possible during each month because of intermittent instrument failure. On the average, at least 90 percent of the data are available. Since 1974 was one of the most severe air pollution years on record (Figure 23), these data probably represent an overestimate of the

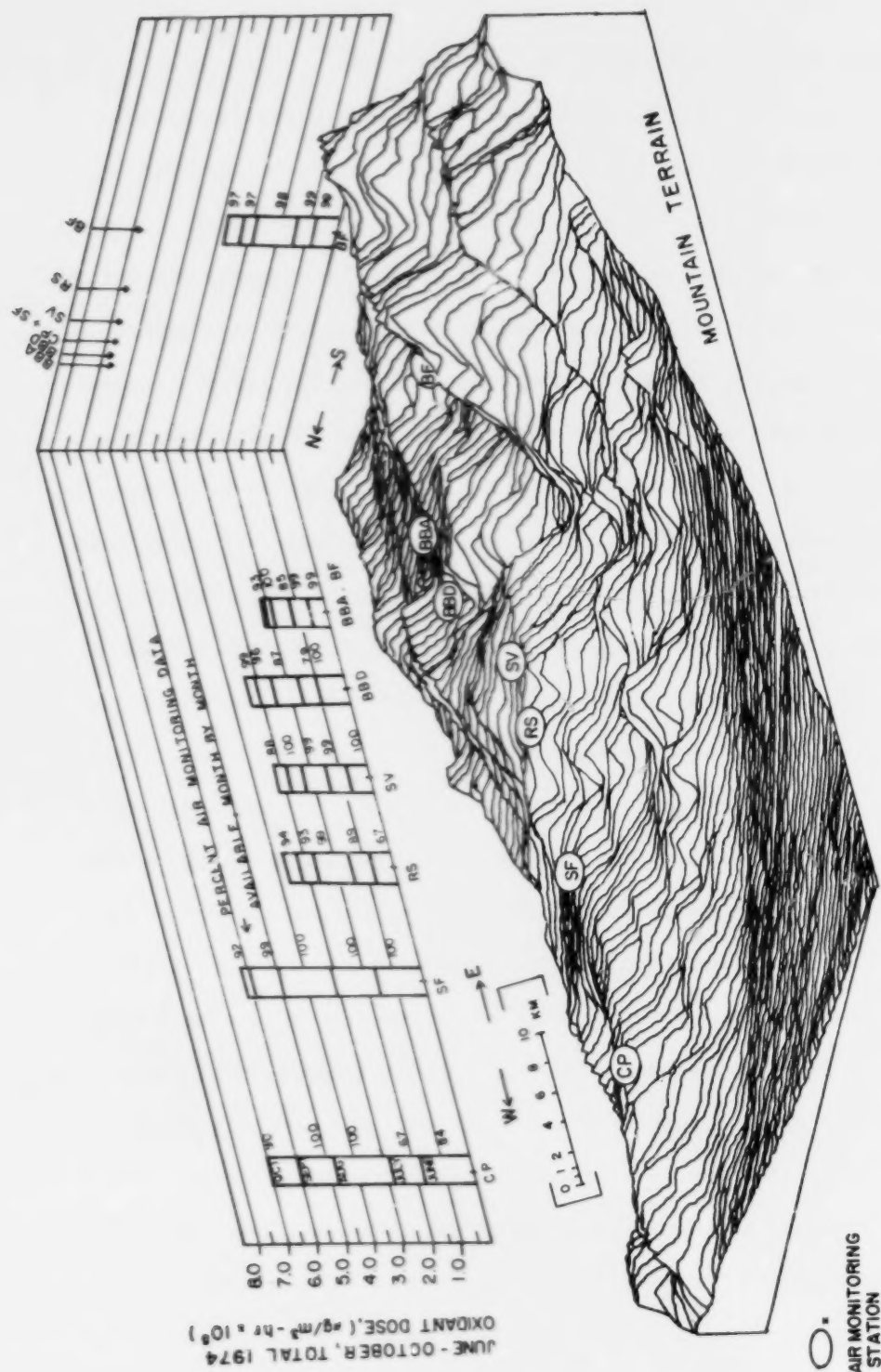


Figure 26. Topographic projection of the San Bernardino Mountains showing monthly summation, June through October 1974, of total oxidant dose at seven monitoring stations. The percent of total data recovered is indicated by month at each station. Locations were: Camp Paivika (CP), Sky Forest (SF) Running Springs (RS), Snow Valley (SV), Big Bear Dam (BBD) Big Bear Air Pollution Control District (BBAPCD) and Barton Flats (BF). (For absolute values, oxidant concentrations and doses might be multiplied by 0.8 to comply with a new, tentative calibration procedure.)

average doses along this gradient in previous years.

The influence of terrain likely causes the rapid decline in dose between Sky Forest (SF) and Snow Valley (SV) because the elevation gradually increases from 1661 m (5,450 ft) to 2052 m (6,750 ft). The slight dose increase at Big Bear Dam (BBD) occurs because the monitoring station is in a notch which channels air flow at the top of a major canyon leading up from the basin. The terrain along the interval between BBD and the Big Bear Air Pollution Control District Station (BBA) is mainly lake surface. Barton Flats (BF) monitoring station is located on the forested north slope of the Santa Ana River drainage and is exposed to the unimpeded afternoon up-canyon flow of polluted air. The information in Figure 26 does not adequately represent the complete eastward extent of pollutant transport in the mixed conifer forest which is necessary to fully define the dose gradient. More important, the western part of the transect generally overlooks the basin and additional data must be obtained by placing stations in a south to north configuration.

In Figure 27, the total hours with oxidant concentration $\geq 157 \mu\text{g}/\text{m}^3$, the Federal Standard, are separated into daylight and night-time hours for August, September, and October, 1974. It is readily apparent that the western, lower elevation monitoring stations receive more night-time hours when oxidant concentrations exceeded $157 \mu\text{g}/\text{m}^3$, especially at Camp Paivika. The greater oxidant concentration at night may be associated with the nocturnal position of the inversion layer which is acting as a reservoir for oxidant as suggested by Edinger (1973). The west to east gradient of decreasing oxidant dose is plainly evident in this analysis, as well as in Figure 26.

MOUNTAINOUS SURFACE WINDFLOW AND POLLUTANT DISPERSION

Earlier studies by Edinger et al. (1972) have demonstrated a natural bond between fire meteorology and air pollution research in terms of kinds of data and data collection techniques required. In the case of air pollution studies, it is important to understand the relationship of terrain to surfaced wind flow and pollutant dispersion. To integrate the complexities of terrain effects on surface flow, a mathematical wind model was formulated by the Fire Meteorology Project (Ryan, 1974). The need for a model is magnified by the lack of meteorological observations in mountainous areas. Because of the lack of observational data, the model was designed to predict winds at remote locations if only sky condition, 850-mb data, and terrain height were available for input. If other data are available, the model is designed to incorporate them.

The model design is based on the premise that mountain winds are a result of the vectorial sum of component winds generated by several different mechanisms and factors. Component factors included in the model are valley-mountain wind, slope wind, sea breeze, larger scale pressure-gradient induced winds, and the sheltering and diverting effect of the terrain.

The detailed terrain effects on wind flow (Figure 28) were computed by the model for 1300 PST on August 31, 1974 for a limited area (see Box Figure 29). Detailed terrain effects on wind flow for the entire area (Figure 29) are not modeled because of lack of data at the present time.

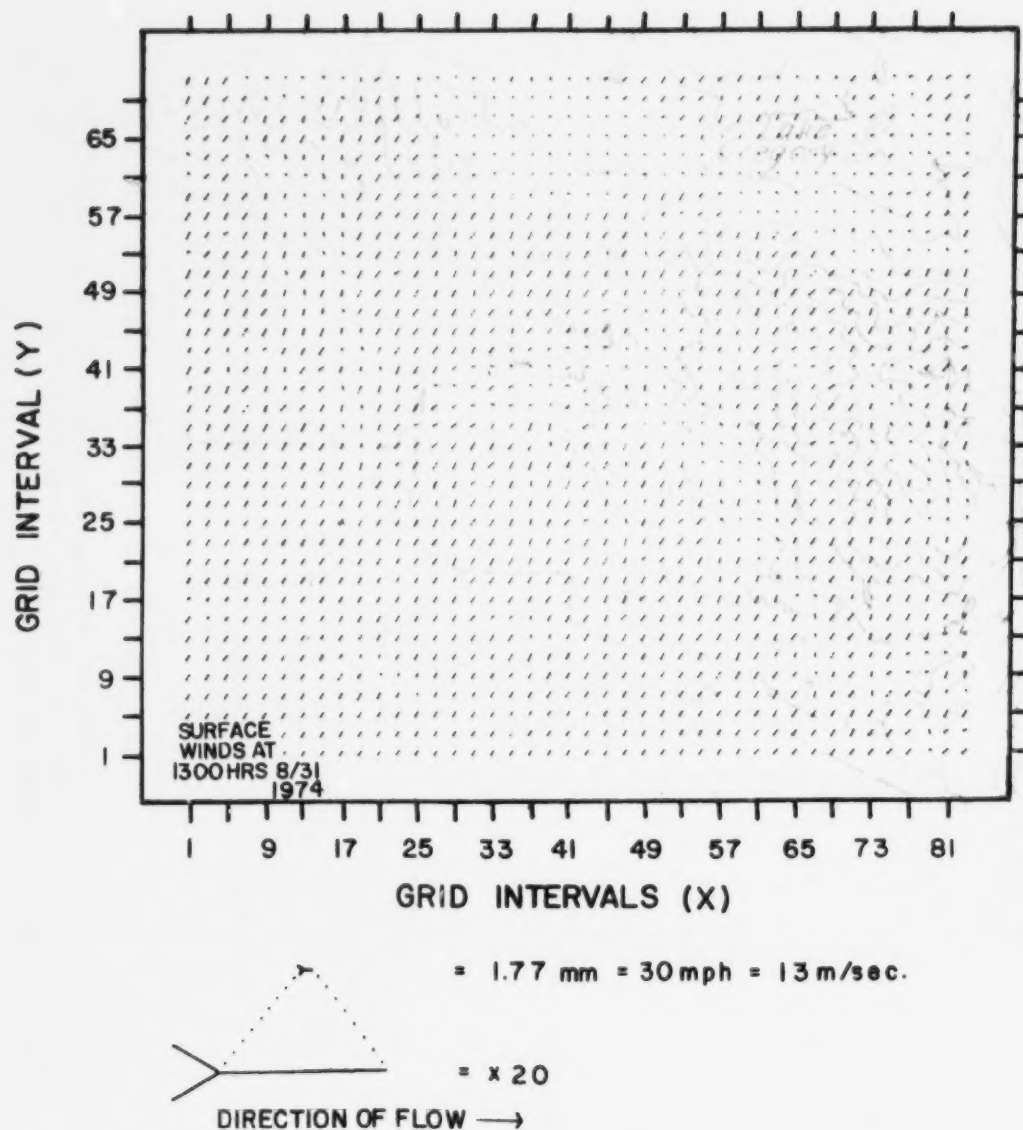


Figure 28. Surface wind fields generated from a computer model for 1300 hr PST, August 31, 1974, for a limited portion of the study area (see caption in next figure).

The synoptic conditions on August 31 resemble a class 4 day of relatively low air pollution potential (McCutchan and Schroeder, 1973). A surface thermal trough was over the desert, and a weak 500 mb trough was just off the coast of southern California. Flow aloft was southwesterly, and the sea breeze was strong from the southwest. The combined effect produced a prevailing surface wind from the southwest with speeds near 6.7 m/sec (15 mph).

Sheltering of the fairly strong southwest flow resulting from the effects of terrain can be seen in several areas such as around grid point $X = 31$, $T = 61$ and around $X = 46$, $Y = 36$. In these areas the strong flow is blocked by higher terrain up-wind. In contrast to these sheltered areas, channels through which strong winds are allowed to flow are evident, such as near grid point $X = 16$, $Y = 66$. Examples of change of direction caused by terrain effects are also displayed such as at gridpoint $X = 21$, $Y = 61$. Changes in wind direction are the result of three different terrain effects: mechanical diversion, wind component produced by differential heating on slopes, and wind component produced by differential heating in valleys.

Observed prevailing surface winds were south to southwest over the entire area (Figure 29). Variation from the prevailing direction owing to terrain influence is evident at Converse. The east-west orientation of Santa Ana Canyon is responsible for the west wind at Converse.

The hourly average of total oxidant concentrations at 1200, 1300, and 1400 hr, the hours before, during, and after the wind observations, are indicated in Figure 29 where monitoring stations were present. For

example, the concentrations at Sky Forest were 235, 235, 353 $\mu\text{g}/\text{m}^3$ for the three consecutive hours. The expected increases of concentrations to a daily maximum sometime after 1400 are evident at all six monitoring stations. When detailed wind fields can be obtained from the model for the whole mountain area it will be possible to evaluate the relationships of flow patterns and pollutant dispersion in relation to forest vegetation injury.

PROCESSES IN ECOSYSTEMS -- IMPACTS ON FOREST VEGETATION INJURY, MORTALITY, AND LITTER ACCUMULATION

Oxidant Dose/Vegetation Injury Response

Chronic injury to vegetation in the San Bernardino Mountains is being inflicted upon a complex mosaic of forest types. These forest types exist along gradients of increasing elevation and decreasing rainfall in a west to east direction. In a similar way, oxidant air pollutants at adverse concentrations and durations decrease from west to east. Differences in such common environmental variables as soil moisture availability, air temperature, relative humidity, and wind have an important influence on degree of plant sensitivity to oxidant pollutants. Ozone is of particular interest because it is primarily responsible for injury to conifers, as determined from controlled fumigations (Miller and Milligan - in preparation). The role of other oxidants, e.g., PAN and NO_2 , assumes more importance with broadleaf trees, shrubs, and with herbaceous understory plants.

The purpose of this study is to define the relationship between

oxidant (particularly ozone) dose and amount of chronic injury (Figure 30) to individual species comprising the mosaic of vegetation types along the west-east gradient of decreasing levels of oxidant pollutants. An integral part of this task is to gain an understanding of the influences of other environmental variables which may condition plant sensitivity; the role of other stresses acting in concert with chronic oxidant injury to cause mortality is also of special interest.

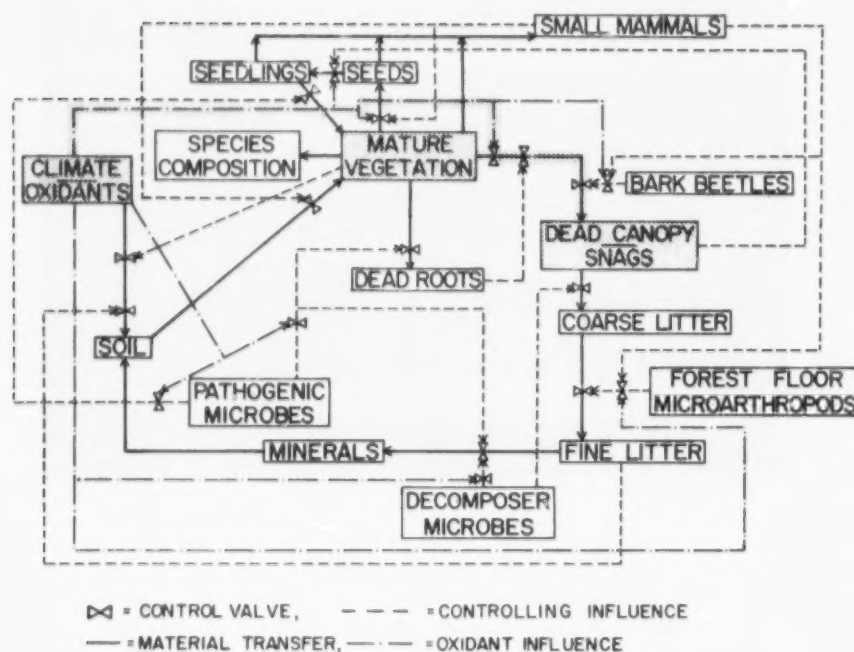


Figure 30. Oxidant dose/vegetation injury subsystem.

Interpretation of Dose-Injury Observations Following Chronic Exposure
of Ponderosa and Jeffrey Pines to Ambient Total Oxidants ---

Two injury rating systems have been employed to provide an index of the amount of oxidant injury. The first system is employed with container-grown seedlings and with saplings less than 10 cm dbh, where the trees are usually small enough so that needle complements can be reached and inspected from the ground. Needles are inspected closely to determine the amount of chlorotic mottle, necrosis, and abscission (Figure 31). Each of the three symptoms are rated as: none = 0, very

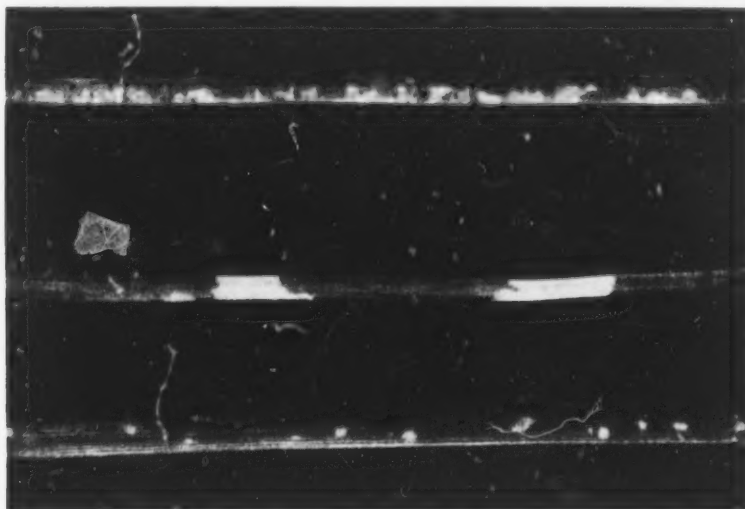


Figure 31. Chlorotic mottle (top), necrosis caused by an experimental ozone fumigation (middle), and superficial necrotic flecks not associated with oxidant injury but rather winter weather (lower).

slight = 1, slight = 2, moderate = 3, and severe = 4. The worst possible score for a single needle complement is 12 and comparisons of complements of the same age from tree to tree form the basis for

evaluation of injury differences. Following chronic injury, the current year and one-year-old needle complements are the only ones remaining. With the seedling-sapling injury evaluation, the higher scores mean greater injury.

The second system is employed only with trees 10 cm dbh and larger in the field and was contrived as a "penalty score or index" system which would be useful to forest managers. Most of the elements making up this score must be determined by binocular inspection of each tree. With this system, the higher scores mean less injury (Miller, 1973a).

Dose-injury observations of ponderosa saplings --- From 1968 to 1973, three nearby groups of 10 ponderosa pine saplings averaging 18 years of age were each subjected to a different treatment: activated charcoal-filtered air in a greenhouse, unfiltered ambient air polluted with oxidants in a second greenhouse, and polluted ambient air outside of the greenhouses. The abbreviations FAH, AAH, and AAO represent each treatment in the order named above. The differences in growth, needle biomass retained, and needle injury symptoms among these three treatments are described in the following section: "Oxidant Effects on Tree Growth."

The AAO treatment in this experiment offered the opportunity to observe the rate of symptom development on current and one-year-old needles in relation to total oxidant dose. In addition, the rate of current year needle growth (cm) was measured (40 needles per tree monthly) to determine (a) the relationships of season to inception and completion of needle elongation, (b) the time of appearance and

intensity of needle symptoms, and (c) the accumulated oxidant dose associated with needle injury. In Figure 32, the data for three years with complete records, 1969, 1970, and 1971, are combined. Trees growing outside greenhouses began to show slight injury to current year needles before needle elongation was completed (between Julian days 200-225, July 19 to August 13). Injury continued to increase on

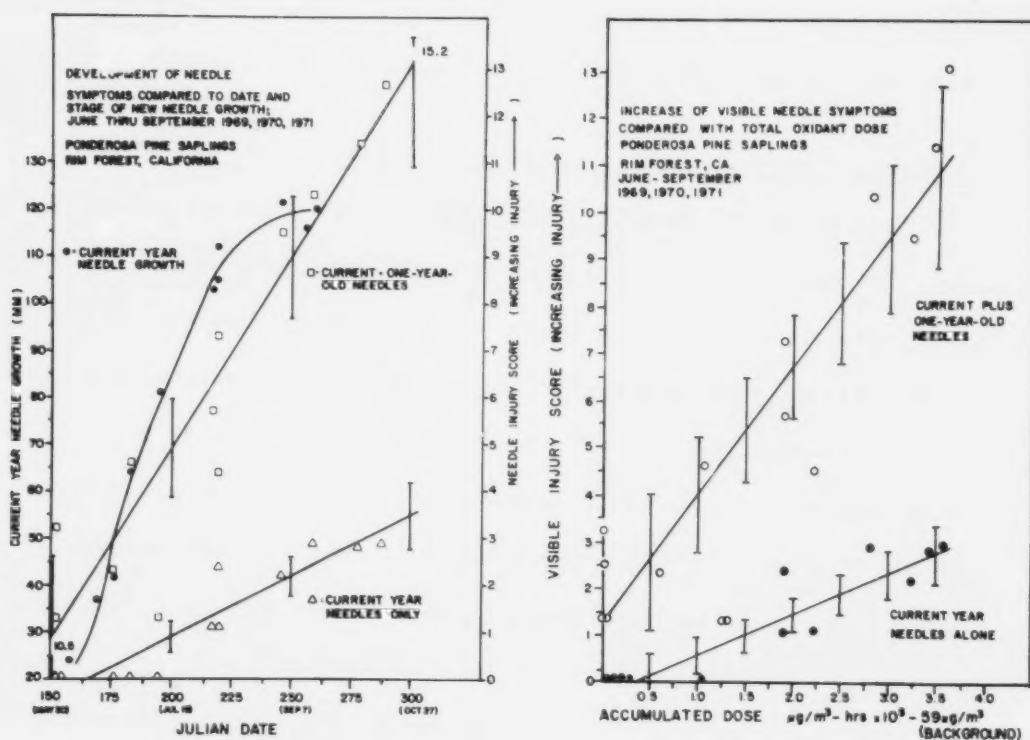


Figure 32. Development of oxidant injury symptoms on current, and current plus one year old, needles of ponderosa pine saplings, in relation to stage of current year needle growth and time during the summer season (left) and in relation to total dose of oxidant (right). (For absolute values, oxidant dose might be multiplied by 0.8 to comply with a new, tentative calibration procedure.)

current year needles for the duration of the summer observation period.

In Figure 32 (left), an average of the three years shows that by Julian day 250 (September 7), the current year needles had a score of 2.2 indicating slight chlorotic mottle; there was usually no necrosis and almost always no abscission of current year needles. On the same date, the combined score of the current and one-year-old needles was about 9, suggesting a combination of mottle, necrosis, and abscission scores for one-year-old needles totaling about 7, with current year needles having a score of about 2. The worst score a single needle complement could have is 12. Two-year-old needle complements were rarely present on this group of injured saplings because the abscission of older needles is the most characteristic result of chronic injury. The trees in the filtered air house nearby usually retained at least 4 needle complements.

The accumulated oxidant dose ($\mu\text{g}/\text{m}^3\text{-hrs}$) since June 1, which is associated with the current year, or one-year-old needle injury expressed in Figure 32 (left), can be estimated by transferring the injury score to Figure 32 (right). For example, the current year needle score of 2.2 on September 7 is associated with a dose of $2.75 \times 10^5 \mu\text{g}/\text{m}^3\text{-hrs}$ total oxidant. The 95 percent confidence limits indicated in both parts of Figure 32 may not encompass all of the variation because they assume that 100 percent of the air monitoring data were available; on the average, about 90 percent was available. Other precautions must be introduced when interpreting the dose response in Figure 32. As indicated in Figure 24, the frequency of pollution episodes is random so the accumulated dose is a composite of

high, moderate, and low dose days. The relative injury-inducing effect of different dose sequences is unknown. The three years of data which comprise Figure 32 are not sufficient to sample the variation involved. It is also assumed that visible injury increases by equal intervals or units from the first visible symptoms to the most severe. Further investigations will hopefully determine the true form of the dose-injury curve. These investigations must also evaluate the controlling influences of soil moisture availability and other important micro-climatic variables on the development of injury. Changes of needle sensitivity to ozone have been observed to occur throughout the growing season when container-grown plants were fumigated (Miller and Milligan, In Manuscript).

Observations of Injury in 1974 to Ponderosa and Jeffrey Pines and Black Oak at 19 Study Sites Along a Gradient of Decreasing Oxidant Dose ---

In September, October, and early November, 1974 all tree species at 19 major study sites or plots were scored individually by binocular inspection. The data from conifers could be obtained this late in the season, however the single most important deciduous species, black oak, was also evaluated during 3 days, August 28-31, to distinguish between oxidant injury symptoms and natural autumn senescence of leaves. The visible injury on oaks observed in August, 1974, is reported here. The details of the scoring method have been described (Miller, 1974). [The higher the score, the smaller the injury.]

The injury to black oak as of August 31, 1974, at several representative study sites, along with the June through August accumulated dose at nearby monitoring stations, is shown in relation to the topo-

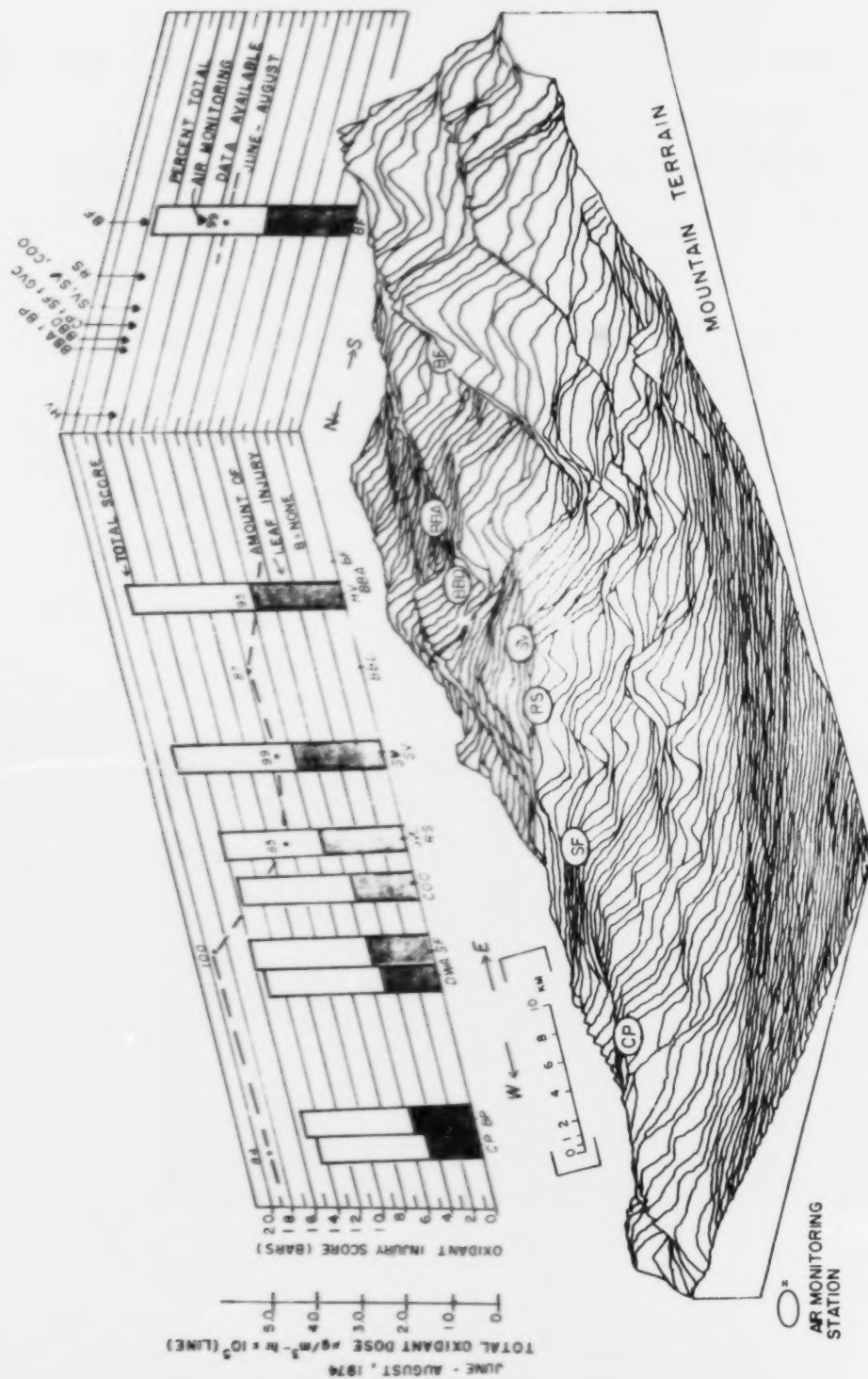


Figure 33. Topographic projection of the San Bernardino Mountains, showing a comparison of oxidant injury to black oaks at major study sites, August 31, 1974, with accumulated total oxidant dose, June-August, measured at nearby monitoring stations. (For absolute values, oxidant dose might be multiplied by 0.8 to comply with a new, tentative calibration procedure.)

graphic projection of the San Bernardino Mountains (Figure 33). The darkened portion of the bar representing oak injury is for leaf chlorotic mottle and interveinal necrosis (Figure 34). A score of 8 means no injury. The remaining portion of the score is the sum of scores for leaf complement, leaf size, and twig mortality, not shown separately. These data suggest that oak shows no injury symptoms when the accumulated June through August dose does not exceed about $2.0 \times 10^5 \mu\text{g}/\text{m}^3\text{-hr}$, or from around Snow Valley eastward. It is also interesting to note that a frost in late May killed all the emerging foliage east of a point midway between Camp O-ongo and Snow Valley. Frost damage increased with elevation. The frost-killed leaves were quickly



Figure 34. Examples of oxidant injury, chlorotic mottle followed by interveinal necrosis, to leaves of black oak, Quercus kelloggii.

replaced by new foliage; it is difficult to assess how this may relate to subsequent levels of oxidant injury to oak.

The distribution of ponderosa and Jeffrey pines into various injury classes (Figure 35) with respect to the distance of the study site along the gradient of oxidant dose (June through September) is illustrated above the topographic projection in Figure 36. It is important to realize that the 1974 distribution into injury classes is also a product of earlier years when the oxidant levels were not always as high as in 1974. The trend towards greater numbers in the very slight (29-35) category is quite evident in the eastern plots receiving

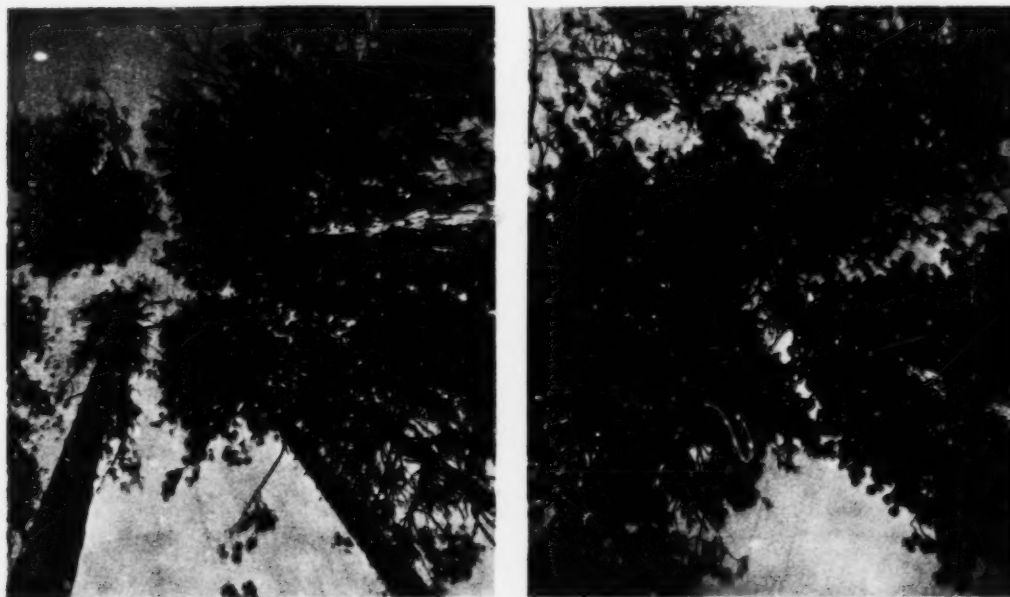


Figure 35. A fish eye lens view of the crowns of severely oxidant injured ponderosa pines (left) with another stand having slight injury (right). Each tree is scored for needle retention, needle condition, needle length, and branch mortality by binocular inspection.

lower doses, e.g., Holcomb Valley (HV).

The assumption has been made that ponderosa and Jeffrey pine respond similarly to oxidant. Ponderosa pine is replaced by Jeffrey pine in the natural stands east of Camp O-ongo (COO) and at Barton Flats (BF). The validity of this assumption can be partially verified by examining the distributions of the two species where they intermix at Barton Flats (BF Figure 36). These data indicate reasonable similarity at a common site, but the influence of other environmental variables which change continuously along the oxidant gradient, e.g., soil moisture availability, air temperature, and humidity, must be examined more intensively to understand how they influence oxidant susceptibility.

Trends in Oxidant Injury and Mortality to Conifer Species in the 18 Major Study Plots from 1973 to 1974 ---

The first evaluation of oxidant injury to all tree species in the new study plots was completed in September and October, 1973. The second evaluation in 1974 offered the first opportunity to assess trends of tree injury and mortality. In Table 6, the plots are arranged in the order of decreasing injury according to the 1974 average injury score for all ponderosa or Jeffrey pine in each plot. In the 12 plots categorized as "severe" and "moderate", all but six showed a lower score (increased injury) which was significant (with a probability that 95 times out of 100 the difference is not due to chance). Among the remaining 6 plots classified as "slight", "very slight", or "no visible" injury, there were three significant increases, one insignificant increase, and two decreases, one significant and one insignificant.

TABLE 6. OXIDANT INJURY SCORES AND MORTALITY RATES OF PONDEROSA AND JEFFREY PINES
AT 18 MAJOR STUDY PLOTS, 1973-1974.

Plot ^a	Species	Tree Density ^b	Average injury Score	Mortality Rate (%)		Accum. Mortality (%)	Injury Description
				1973	1974		
SCR	JP	28	12.4	0.0	0.0	0.0	Severe
COO	PP	90	15.1	0.0	0.0	0.0	
SF	PP	144	13.3	0.8	0.8	1.6	
UCC	PP	309	15.5	0.0	1.5	1.5	Moderate
BP	PP	236	16.3	2.7	2.7	5.5	
CP	PP	217	17.1	0.0	3.1	3.1	
DWA	PP	168	19.9	1.2	0.0	1.2	
TUN 2	PP	122	19.5	0.0	1.4	1.4	
CA	PP	112	25.6	0.0	1.5	1.5	
BF	PP	200	21.4	3.7	3.7	7.4	
BF	JP	124	21.0	3.6	3.6	7.3	
SV	JP	129	22.1	0.0	1.0	1.0	
GVC	JP	43	21.8	0.0	1.5	1.5	
CAO	JP	192	21.7	0.8	7.2	8.0	Slight
BL	JP	186	29.4	0.0	0.0	0.0	Very Slight
NEGV	JP	120	33.1	0.0	0.0	0.0	
HB	JP	130	44.0	0.0	0.9	0.9	No Visible Symptoms
SC	JP	56	41.3	0.0	0.0	0.0	
HV	JP	193	46.4	0.0	0.0	0.0	

^a See Figure 1 for plot locations.

^b Number of trees/hectare

^c Significant 95 times out of 100. (comparisons valid only between years at a single plot.)

The general increase in injury (lower scores) in the "severe" and "moderate" plots is probably related to the increase in June through September, 1974 dose, (Figure 23). Tree mortality among ponderosa and Jeffrey pines was about the same in 1973 and 1974. The largest mortality occurred in the "moderate" injury category. Perhaps these populations still retain greater numbers of the more susceptible individuals. If the remaining trees comprising the populations in the more severely injured plots are more oxidant tolerant, the mortality rate might be less than for other plots. The percentages of dead trees reported in Table 6 include only those killed directly by oxidant or the oxidant-bark beetle interaction. Other small trees were killed due to snow breakage but were not included.

Mortality of ponderosa and Jeffrey pine can be evaluated over a longer time period from data gathered from a nucleus of 50 trees at Dogwood (DWA) and Barton Flats (BF). These plots were first established in 1968 and then expanded to their present size in 1972. The accumulated percent of mortality in these original populations from 1968 to 1974 was 22 and 24 percent at BF and DWA, respectively. The future prospects seem very dim when the trend of increasing oxidant dose each year, Figures 22 and 23, is examined.

In Table 7, the average injury scores for white fir, incense cedar and sugar pine are listed with plots in the same order of decreasing injury employed for ponderosa and Jeffrey pine in Table 6. We do not yet have enough experience to define the score ranges for these species with meaningful verbal descriptions. The trend of scores from 1973 to 1974 for these species was not definite, and no mortality was

TABLE 7. OXIDANT INJURY SCORES OF WHITE FIRS, INCENSE CEDARS,
AND SUGAR PINES AT 18 MAJOR STUDY PLOTS, 1973-1974.

Plot	White Fir Average Injury Score		Incense Cedar Average Injury Score		Sugar Pine Average Injury Score	
	1973	1974	1973	1974	1973	1974
SCR	52.9	52.1	-- ^a	--	--	--
COO	47.2	47.2	30.3	29.7	--	--
SF	40.7	42.5	24.4	25.2	35.5	34.6
UCC	--	--	--	--	--	--
BP	--	--	27.4	27.1	--	--
CP	--	--	--	--	--	--
DWA	37.9	37.1	20.7	24.2* ^b	60.0	44.7
TUN 2	49.3	51.5	--	--	37.6	38.0
CA	55.6	54.8	--	--	39.0	27.8
BF	--	--	--	--	--	--
SV	52.7	54.0	--	--	--	--
GVC	53.6	52.0	29.2	27.6*	36.0	30.7*
CAO	48.6	42.7	--	--	--	--
BL	58.0	56.4*	--	--	--	--
NEGV	66.6	64.5	--	--	--	--
HB	48.7	51.5	--	--	--	--
SC	62.3	59.2	--	--	--	--
HV	63.7	61.8	--	--	--	--

^a Blank means that the species is not present.

^b Significant, 95 times out of 100.

observed. The larger decreases in sugar pine scores are difficult to interpret because of the small numbers involved, e.g., only 3-15 trees per plot.

Oxidant Injury to Broadleaf, Woody Vegetation ---

Both shrub and tree species were inspected throughout the summer and autumn. Skunk bush (Amorpha californica) was the only shrub layer species which showed ozone-like injury. Among the trees, the oaks (Quercus crysolepis and Q. wislizenii) and dogwood (Cornus nutalli) displayed no definite symptoms but black oak (Quercus Kelloggii) began to show chlorotic mottle in 1974 with some interveinal necrosis as early in the growing season as August 9, 1974 in the western section of the study area.

Herbaceous Vegetation ---

During the spring and summer, 1974 all 18 vegetation plots and adjacent areas were routinely inspected as new plants emerged and flowered. Ozone or PAN type symptoms were observed on 11 species: Bromus orcuttianus, Elymus glauca, Osmorhiza chilense, Gallium aparine, Erigeron breweri, Potentilla glandulosa, Solidago sp., Vicia californica, Artemisia douglasiana, Silene verecunda, and Collomia grandiflora. Seeds were collected from six of the above species which occur in the greatest abundance. Ozone and PAN injury symptoms are to be confirmed by fumigation experiments on young plants grown in the greenhouse from this seed.

Oxidant Effects on Tree Growth

Objectives and Approach ---

The vegetation subcommittee has investigated three general parameters of vegetation in an effort to contribute information to the understanding of the impact of oxidant air pollutants on the mixed conifer forest ecosystem as shown in Figure 37. These parameters are growth of vegetation, composition of the vegetation, and succession of the vegetation. We first need to know how air pollutants affect the growth of vegetation, because this will affect the ability of different plant species to compete with one another for the resources

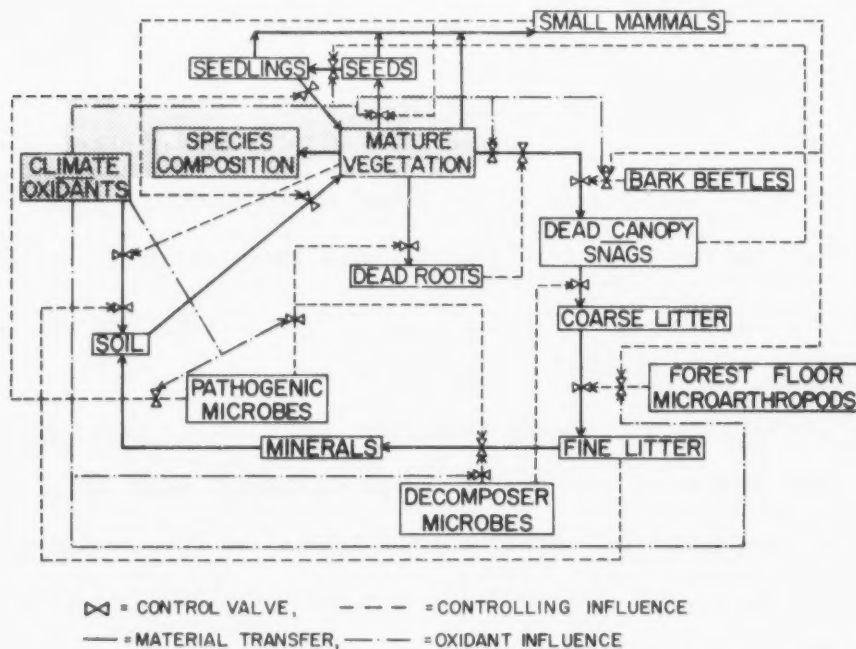


Figure 37. Vegetation growth subsystem.

they require (ecosystem dynamics). As a result of this competition, particular species compositional patterns occur (ecosystem structure). Over time, these compositional patterns change and result in vegetational succession (ecosystem behavior).

Annual Growth of Ponderosa Pine Trees ---

Oxidant effects on height growth in a greenhouse --- The impact of oxidant air pollutants on height growth and diameter growth of ponderosa pine has been investigated. Height growth was investigated in a study of three groups of ten ponderosa pine saplings which were exposed to three treatments: ambient air outside, AA0; ambient air greenhouse,

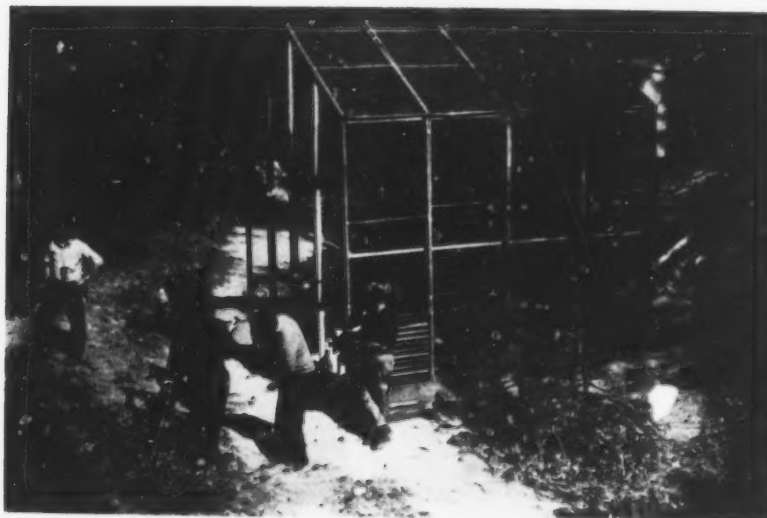


Figure 38. Aluminum framed greenhouse covered with transparent plastic film and provided with a carbon filter-blower (upper rear). Carbon filters were removed to obtain the ambient air treatment in a second house.

AAH; and carbon-filtered air greenhouse, FAH (Figure 38). The exposures to each treatment lasted from April 15 to November 15, during 1969 to 1973. These naturally seeded trees were located in a heavily damaged area 0.4 km west of Rim Forest, California. A nearby monitoring station documented the oxidant dose during June through September each year (Figure 23). At the outset of the experiment in August 1968, most trees retained only 1967 and 1968 annual needle complements with severe oxidant injury symptoms, namely, chlorotic mottle, necrosis and

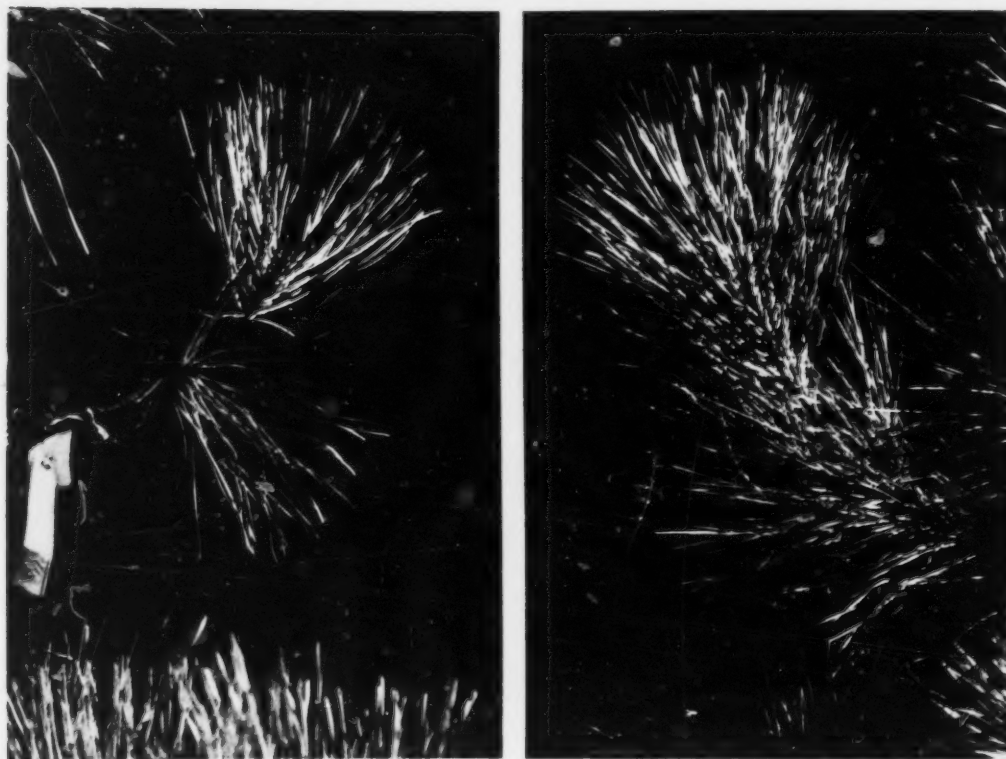


Figure 39. The appearance of a typical upper crown branch (left) from a ponderosa pine exposed to ambient oxidant air pollutants in a greenhouse for 5 years shows fewer and shorter needles. A similar branch exposed to carbon filtered air (right) retains more needles which are longer; at the outset of the experiment, this branch resembled the one on the left.

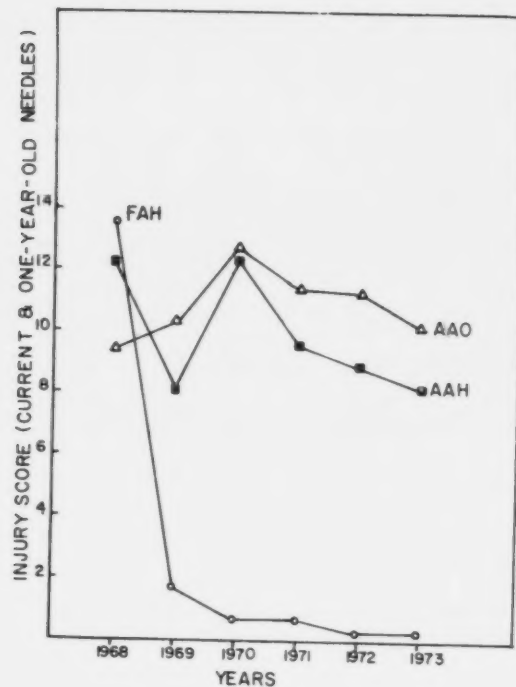


Figure 40. Injury score of current plus one-year needles, 1968-1973, from ponderosa pine saplings maintained in filtered (FAH), or unfiltered air greenhouse (AAH), and an outside ambient air treatment (AAO).

premature abscission of needles shorter than normal (Figure 39, left). In the following years, the new needles growing in the FAH treatment failed to develop injury symptoms and were distinguished by their longer length, healthy green color (Figure 39, right) and lower oxidant injury scores compared to the AAH and AAO treatments, Figure 40. The slightly lower level of needle injury to AAH than to AAO suggests that enclosure in a force-ventilated greenhouse without air filtration had some positive benefit compared to AAO saplings growing outside and adjacent to the greenhouses.

At the end of the 1973 growing season, the saplings were harvested in order to explore other differences among the treatments. Needle biomass was compared for internodes of the same age. Increases of needle biomass in the FAH treatment for the one-year-old (1973) needle complement compared to AAH and AAO trees (Figure 41), became significantly greater (95 times out of 100) by 1973. Needles in internodes older than 2 years were completely absent in the AAH and AAO treatments. The numbers of needle fascicles remaining per internode in each polluted air treatment followed the same trend.

The dramatic decrease in needle leaf biomass in the AAO and AAH

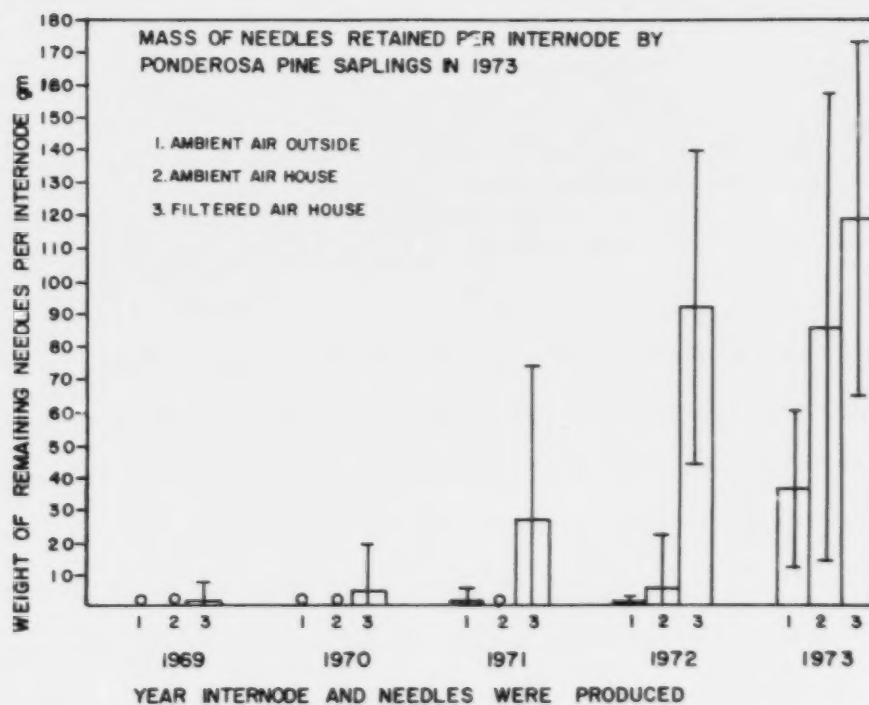


Figure 41. Average dry weight of all needle fascicles per internode in filtered (FAH), or unfiltered air greenhouse (AAH), and an outside ambient air treatment (AAO).

treatments represents severe reductions of photosynthetic capacity. Conversely, as more leaf biomass was produced in the FAH treatment, more carbohydrates could be produced and used for the growth of woody tissue. After a lengthy lag period, the lengths of the terminal shoot (Figure 42, upper) and first order branches (Figure 42, lower) of the upper half of the crowns of trees in the FAH treatment increased significantly (95 cases out of 100). Terminal and branch growth of trees in the AAH and AAO treatments remained the same or lower, Figure 42. An analysis of radial growth of the saplings in this experiment is now in process.

Oxidant effects on radial growth by age classes --- The influence of oxidant air pollutants on radial growth has been investigated in two other studies. The first of these was a comparison of the radial growth of ponderosa pine in environments characterized by low air pollution (1910-1914) and high air pollution (1941-1971). Two populations of trees occurring near the Dogwood plot were used in the study. One population ranged in age from 52 to 71 years in 1972 and the other from 20 to 39 years. Nineteen dominant trees were selected from each population and an increment core sample was removed from the south side of each ring. Ring widths were measured on these cores to the nearest 0.01 mm with a dendrochronograph. An average ring width was calculated for the 52 to 71 year old population for rings produced from 1910 to 1940 (Table 8). This period was characterized by low oxidant concentrations in the San Bernardino Mountains. During this period, the trees in the 52 to 71 year old population became established and pro-

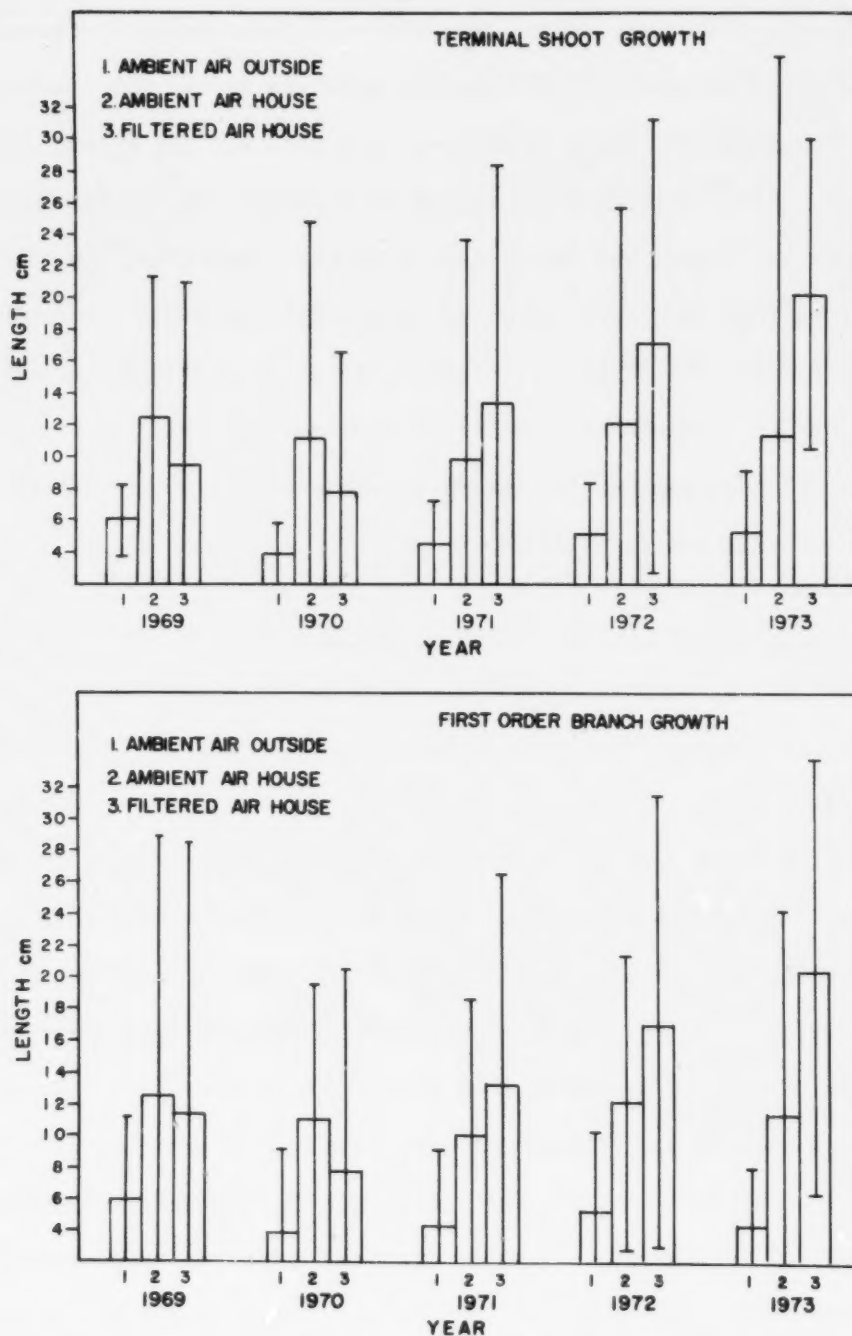


Figure 42. Annual growth of terminal shoot (upper) and first order branches (lower) in upper half of sapling from ponderosa pine maintained in filtered (FAH), or unfiltered air greenhouse (AAH), and an outside ambient air treatment (AAO).

TABLE 8. AVERAGE ANNUAL RADIAL GROWTH OF 19 PONDEROSA PINE TREES IN TWO LEVELS OF OXIDANT AIR POLLUTANTS.

HIGH POLLUTION		LOW POLLUTION	
Age ^a (Years)	Average Radial Growth (cm) 1941-1971	Age ^a (Years)	Average Annual Radial Growth (cm) 1910-1940
20	0.20	60	0.52
21	0.33	55	0.49
29	0.22	55	0.61
22	0.33	57	0.34
25	0.30	64	0.40
35	0.23	63	0.55
27	0.29	60	0.44
28	0.31	65	0.46
35	0.26	60	0.75
22	0.43	71	0.67
39	0.21	63	0.71
35	0.34	71	0.65
29	0.37	66	0.78
33	0.37	63	0.53
35	0.34	60	0.33
35	0.37	70	0.38
36	0.35	61	0.32
36	0.33	62	0.37
34	0.36	59	0.37
Average	30.3	62.4	0.51

^aAge at 1.4 m above ground in 1971.

duced 20 to 39 annual rings. An average annual ring width was calculated for the 20 to 39 year old population for rings produced from 1941 to 1971 (Table 8). This period was characterized by high oxidant concentrations in the San Bernardino Mountains. During this period, the trees in the 20 to 39 year old population became established and produced 20 to 39 annual rings. The average annual rainfall of the period from 1910 to 1940 was 110.9 cm, and from 1941 to 1971 was 117.4 cm. A difference of 0.20 mm in average annual growth occurred between the two periods. Average 30 year old trees grown in the two periods would have diameters of 30.5 cm and 19.0 cm (Figure 43). The difference in these diameters

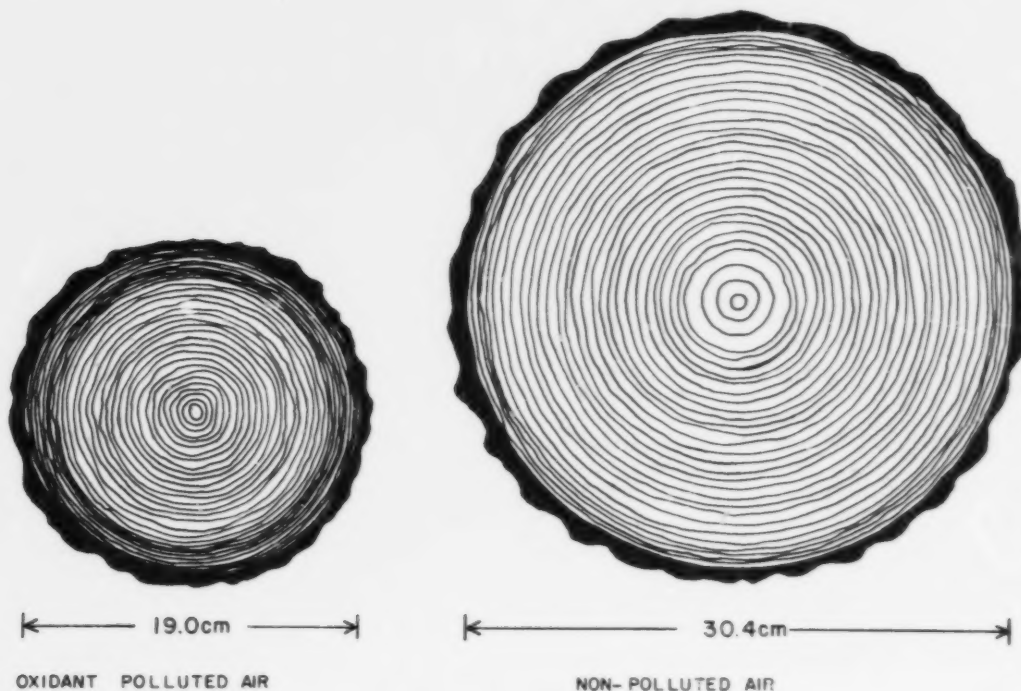


Figure 43. Calculated average cross-sections of two 30-year-old ponderosa pines at breast height grown in polluted air (left) and in non-polluted air (right) based on radial growth samples from 1941-1971 and 1910-1940.

is attributed to the influence of air pollutants during the period from 1941 to 1971. This information, along with the height growth data from the previous study, can be combined to give an approximation of the reduction in volume growth in ponderosa pine trees near the Dogwood plot. An average 30-year-old tree grown under the present air pollution conditions would be 7.0 m tall, 19.0 cm in diameter at breast height and could produce one log 1.8 m long with a volume of 0.047 m^3 (Figure 44). An average 30 year old tree grown in the absence of oxidant air pollutants (i.e., 1910-1940) would be 9.1 m tall, 30.5 cm in diameter and could produce one log 4.9 m long with a volume of 0.286 m^3 (Figure 44).

Radial growth in relation to oxidant injury scores --- A second study of radial growth has attempted to correlate ring width with the oxidant injury score of individual trees near the Dogwood plot. Increment cores were taken from the south side of 102 dominant and co-dominant ponderosa pine trees. Annual ring width was measured to the nearest 0.01 mm on these cores with a dendrochronograph. The correlation between current (1974) annual ring width and current (1974) oxidant injury score and the correlation between current (1974) annual ring width and average oxidant injury score (1969-74) was determined using a regression analysis based on the method of least squares (Table 9).

The low r-values obtained in both tests indicate that crown characteristics assessed by oxidant injury scoring (Miller, 1974) are not closely correlated with radial growth. This result is difficult to understand in view of the general correlation between photosynthetic

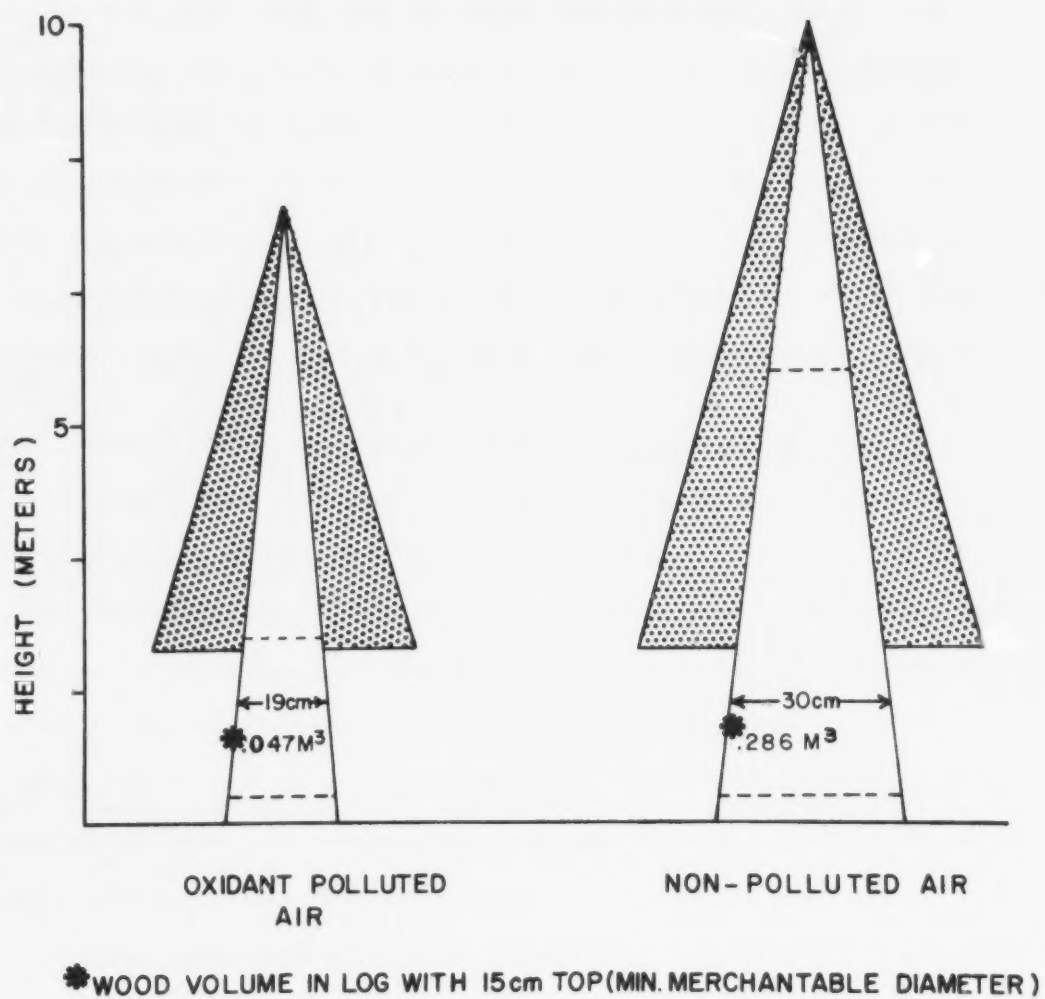


Figure 44. Calculated average growth of 30-year-old 15 cm ponderosa pines in polluted and non-polluted air based on radial growth samples from 1941-1971 and 1910-1940.

TABLE 9. CORRELATIONS BETWEEN PONDEROSA PINE RADIAL GROWTH (Y) IN CENTIMETERS AND OXIDANT INJURY SCORE (X).

<u>Independent Variable</u>	<u>Regression Equations</u>	<u>r</u>
Current year oxidant injury score (1974)	$Y=0.12 + 0.06X$	0.51
Average oxidant injury score (1969-74)	$Y=0.10 + 0.06X$	0.51

area and radial growth in forest trees as discussed by Kramer and Kozlowski (1960). The oxidant injury scoring method used may involve the measurement of characteristics which have little impact on radial growth but contribute significantly to the calculated oxidant injury score (i.e., branch mortality in the lower crown). Further investigation of the influence of air pollution on radial growth is planned in this study. A preliminary attempt at correlating precipitation and oxidant level with ring width was inconclusive (McBride, 1974). A larger sample of tree cores has been collected and the annual ring widths are being measured. Variations in temperature, precipitation, and oxidant level will be used in a principal component analysis (Fritts, 1974) to determine their respective effects on radial growth.

Timber volume decrease in a Jeffrey pine stand since 1952 --- The longest observation of tree decline (not knowingly intended at first to evaluate oxidant injury) began in 1952. One Forest Service plot on Camp Osceola Road, Table 10, has been used as the site for nesting the CAO plot (Figure 1) where the present level of oxidant injury has been

TABLE 10. CHANGES OF TIMBER VOLUME AND PERCENT OF TOTAL JEFFREY PINES IN FOUR BARK BEETLE RISK CLASSES AT TWO CONTROL PLOTS EXCLUDED FROM SANITATION SALVAGE LOGGING BETWEEN 1952 and 1972 AT BARTON FLATS IN THE SAN BERNARDINO NATIONAL FOREST. ^a

Risk classes ^b	Control Plot #1 (JCA Camp, Highway 38)					
	1952		1963		1972	
	Timber volume ^c	Percent of trees	Timber volume	Percent of trees	Timber volume	Percent of trees
Total, all classes	73,040	100	63,530	100	52,730	100
Risk 1 and 2	58,520	87	38,700	73	23,780	55
Risk 3	6,740	7	14,630	13	14,140	16
Risk 4	7,780	5	10,200	7	14,810	20
Snags and current stumps ^d	1	1	11	7	13	8

TABLE 10. CHANGES OF TIMBER VOLUME AND PERCENT OF TOTAL JEFFREY PINES IN FOUR BARK BEETLE RISK CLASSES AT TWO CONTROL PLOTS EXCLUDED FROM SANITATION SALVAGE LOGGING BETWEEN 1952 and 1972 AT BARTON FLATS IN THE SAN BERNARDINO NATIONAL FOREST. (Continued)

Control Plot #2 (Camp Osceola Road)				
	<u>1952</u>	<u>1963</u>	<u>1972</u>	
Total, all classes	120,130	100	113,100	100
Risk 1 and 2	110,830	93	98,080	82
Risk 3	5,990	3	10,170	6
Risk 4	3,310	2	4,410	6
Snags and current stumps	3	2	13	6
				18
				10

^a These data are attributed to the U.S. Forest Service, Supervisor's Office, SBNF.

^b Risk 1 and 2 are vigorous low risk; Risk 3 and 4 indicate decreasing vigor, high risk.

^c Board feet

^d Accumulation during 10-year period

determined (Table 6) as moderate. The JCA Camp plot also described in Table 10 is not more than a mile to the northwest. The increases of Jeffrey pine distributions into the high risk classes, loss of timber volume and mortality rates between 1952 and 1972 all suggest serious stand deterioration even though the present tree scores indicate "moderate" injury. This is an example of the difficulty of using verbal summaries to characterize the "severity" of stand injury. In the stands surrounding these plots, three sanitation salvage logging operations have been carried out since 1952 to remove high risk overstory trees. It is probable that the decline of timber volume in both plots is the combined result of mortality and the failure of the remaining trees to add volume through new growth.

The Climate in the Soil and the Drought Stress

In order to examine the interaction of climate with soil and possible drought-stress which can occur simultaneously with the impact of oxidant air pollution on the ecosystem, the first step is to document the climate in terms of precipitation, the soil moisture regime, the soil temperature regime, and the consequent water balance of the system, as indicated in Figure 45. Soil cores were collected at 23 sites to the depth of hard bedrock, or to a depth of 2.75 m (9 feet), in the spring and fall, for maximum and minimum water content, and for physical and chemical analysis. Water content was determined by weight differences in oven-dried samples, and the total volumetric water content calculated for the entire soil core as corrected for gravel or

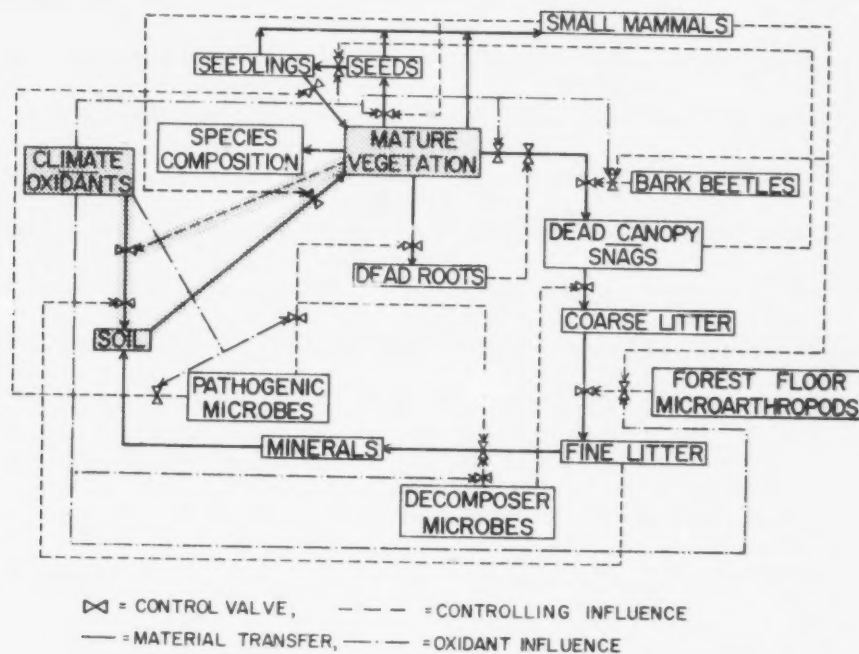


Figure 45. The place of the soil subsystem in the ecosystem.

stones. These data provide a true estimate of soil water storage capacity which is usable by plants.

Soil Moisture ---

Soil moisture-temperature sensors (fiberglass moisture blocks) were installed at depths of 15, 30, 61, 92, 152, 214, 274 cm (6, 12, 24, 36, 60, 84, and 108 inches) in auger holes which were repacked with the same soil to its original thickness and density as much as possible. Readings have been taken every 1 to 3 weeks depending upon the rate of change of the soil moisture since the spring or summer of 1973 (Figure 46). Soil taken from the soil cores was used to calibrate the moisture sensor

readings with water content.

An example of the results obtained at one site from the fiberglass moisture-temperature sensors installed at 23 sites throughout the study area is shown in Figure 47. The moisture curves were obtained by comparison of field readings (conductivity converted to resistance and corrected for temperature by computer) with the same for soil samples from the same site at varying moisture contents. The moisture curves for 3 depths show the drying period from March to October for 1973 and 1974. In both years, the effect of light rains wetting the upper 15 cm (6 inches) of soil during April and May is evident, while rain in May affected the sensor at 91 cm (36 inches) only in 1973. The total amount of rain which produced these effects was only 20 mm (0.79 inches) in



Figure 46. Portable soil moisture meter temporarily attached to fiberglass moisture blocks installed permanently at depths from 15 to 274 cm (left). At the same site are cans for collecting crown drip and screens for collecting litter fall (right).

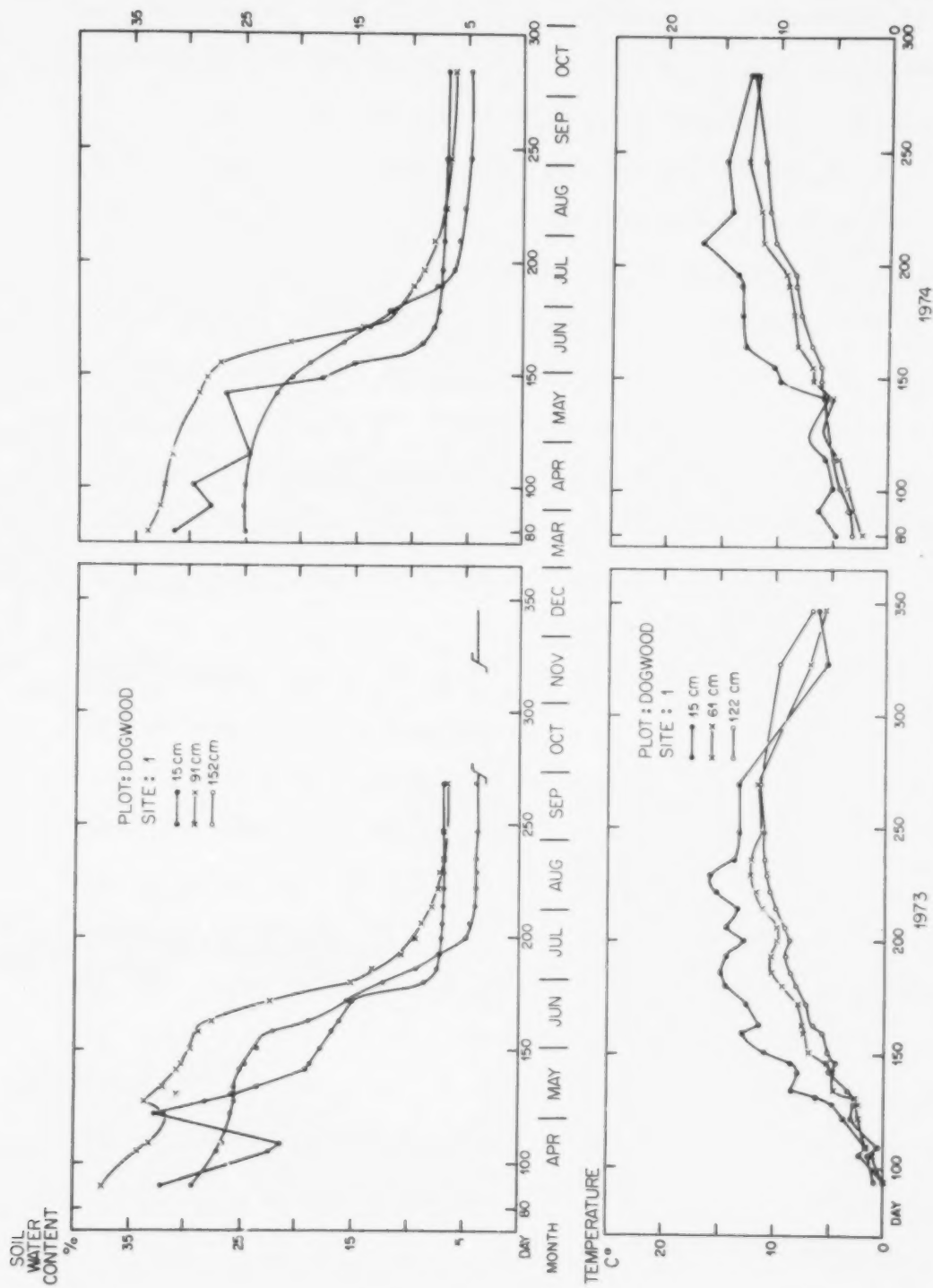


Figure 47. Soil moisture and temperature regime 1973-74 at Dogwood plot.

1973, recorded at Lake Arrowhead about 1.5 km away. In May 1974, rain amounting to only 7.0 mm (0.28 inches) produced the rise in the curve in late May. The sensitivity of the method is quite evident.

The curves show clearly that the maximum rate of water use by the vegetation occurs during June and early July, and that after mid-July, the soil dries very slowly indicating that the upper 150 cm of soil is at or near permanent wilting point. At another site, sensors placed to a depth of 275 cm (9 feet) showed moisture extraction continued slowly into September, suggesting that the forest survives the summer drought by moisture extracted from deep into the decomposed granite substratum. The drastically reduced rate of water use after mid-August indicates that the forest is essentially in a dormant state at least until the first precipitation in autumn.

The spring period during which the soils contain available soil moisture in 1974 is shown by black bars in Figure 48. These data were also obtained from the sensors and indicate that essentially all available soil moisture was exhausted from the soil in 11 plots before mid-August. The date was determined by examination of the computed resistance of the moisture sensors; the first data at which the sensor was found to have a resistance of 100,000 ohms was taken to represent the date after which soil moisture depletion was at a minimum rate. Three of the sites, Heart Bar (HB), Sand Canyon (SC1), and Camp Osceola (CA0) were wet by summer thunderstorms in late July and early August. This rain probably had little effect at Heart Bar as only the upper 30 cm (1 ft) was moistened. However, Sand Canyon and Camp Osceola were wet to a depth of about 1 m at a time when the deep soil moisture was nearly

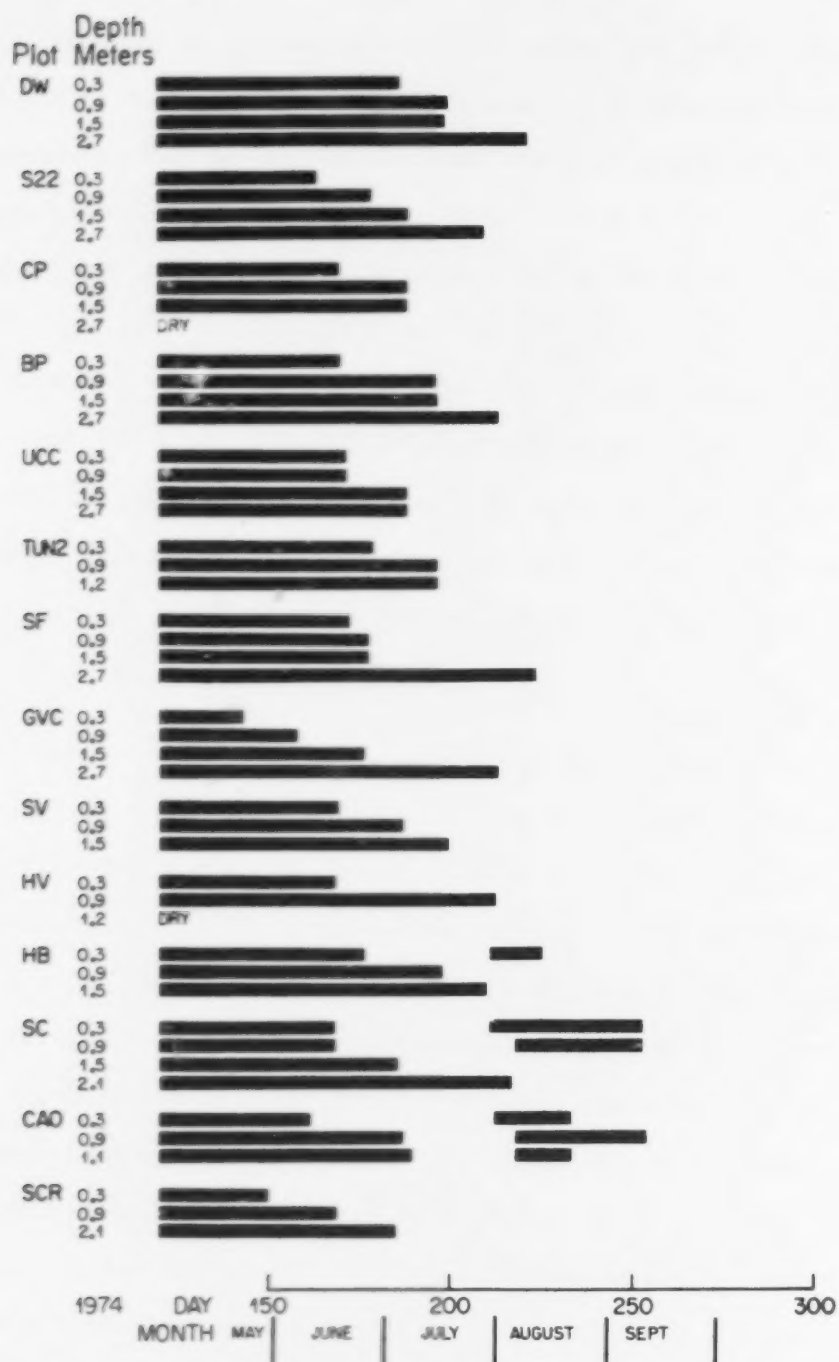


Figure 48. Time intervals during which the soil at various depths contained moisture available for plants during spring and summer 1974.

exhausted. Thus, the period of active growth may be prolonged by summer thunderstorms, which occur mainly in the eastern portion of the San Bernardino Mountains near Big Bear Lake and in the Santa Ana Canyon. August precipitation exceeding 25 mm at Big Bear Lake Dam occurs with a frequency of about 23 percent, while at Lake Arrowhead it is about 14 percent.

The significance of these data in relation to air pollutant impact is that the most dynamic growing period is from early May, when soil temperatures begin to rise, to August when soil moisture is often exhausted. Thus, one could expect the most severe damage to the plants by air pollutants to take place during this period.

Soil Temperature ---

Soil temperature measurement at the Dogwood plot obtained with the soil moisture-temperature sensors are also shown for 3 soil depths in Figure 47, representative of the Lake Arrowhead area. The curves show that the soils were colder in April, 1973 than 1974. The soil temperature during 1973 rose smoothly to a maximum in August; whereas in 1974, soil temperatures were held down by a cold period in May, followed by a sharp rise in surface temperature with the maximum (below the surface layer) delayed into September. A marked soil temperature difference due to aspect is shown by the fact that in September 1974, the soil temperature in the upper part of the soil was 7.7 C higher at plot S22 than the Dogwood plot. Plot S22 is near the Dogwood plot but has a south-facing slope.

Preliminary inspection of the data indicates that in September, at

the Bluff Lake plot, high above Big Bear Lake at an elevation of 2260 M (7400 feet), the soil temperature was 3.6 C lower than at Dogwood; at Holcomb Valley on the desert side of Big Bear Lake it was about 3.8 C higher; and Camp Angelus in the Santa Ana Canyon, but at about the same elevation as Dogwood, was about 2.4 C higher. Detailed comparisons of the soil temperature regimes at all plots will be completed soon.

Air Pollution in Relation to Rainwater Under Pine Tree Crowns ---

To examine the effect of air pollution on the forest floor (litter layers) and the surface soil, the amount, distribution and composition of crown drip under pine trees variously affected by air pollution injury is being studied. Nine ponderosa pine trees at the Camp O-Ongo plot, with oxidant injury ratings of 10 (severe) to 34 (slight), were sampled with random radial lines of collector cans set on stakes at 0.5 m intervals out from the tree trunk to 1.0 m outside the drip line, Figure 46. Precipitation and crown drip were collected and the volume measured at 173 sites, an average of 19 samples around each tree. Of these samples, 66 (7 or 8 per tree) were selected at random and analyzed for calcium, magnesium potassium, sodium, and phosphorus.

Crown drip and the amount of precipitation interception --- Crown drip was collected immediately following the first period of precipitation in the fall which occurred in the last week of October 1974 under ponderosa pine trees ranging from severely damaged by air pollutants (oxidant injury score = 10) to only slightly affected (injury score = 34) on the Camp O-Ongo plot. An interesting observation is that the crown drip under the

trees, 1.0 to 3.0 m from the trunk exceeded the precipitation measured 1.0 to 2.0 m outside the crown line of the tree. The precipitation averaged 79.2 mm (3.12 inches) while the average crown drip was 90.2 mm (3.55 inches). The difference is highly significant since statistical analysis indicates this difference to be real in 99 out of 100 cases. Generally, interception of precipitation by vegetation is thought to decrease the amount of water reaching the ground surface. However, in these mountain regions precipitation is generally accompanied by considerable wind, and apparently the fact that the rain is falling at an angle, rather than vertically, accounts for the fact that less than the total precipitation reaches the ground between the trees. Presumably the true precipitation, if it were measured above the forest, would be between the two values of 90.2 and 79.2 mm.

Plant nutrient concentrations in tree crown drip --- Collected crown drip and precipitation were analyzed for calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), and phosphorus (P). The most striking feature of the results is the increase in total cations (Ca, Mg, K, and Na) with decreasing distance from trunk, although some high values were found (>20.0 mg/l) up to 2.0 meters from the trunk. It appears that the precipitation drips from ponderosa pine needles to limbs near the center of the tree crown before falling to the ground. The high values appear to be from drip from the limbs, rather than directly from needles. The general relationship is shown clearly in Figure 49.

This variation apparently obscures any effect that the air pollutant injury may have on the composition of the crown drip. The content

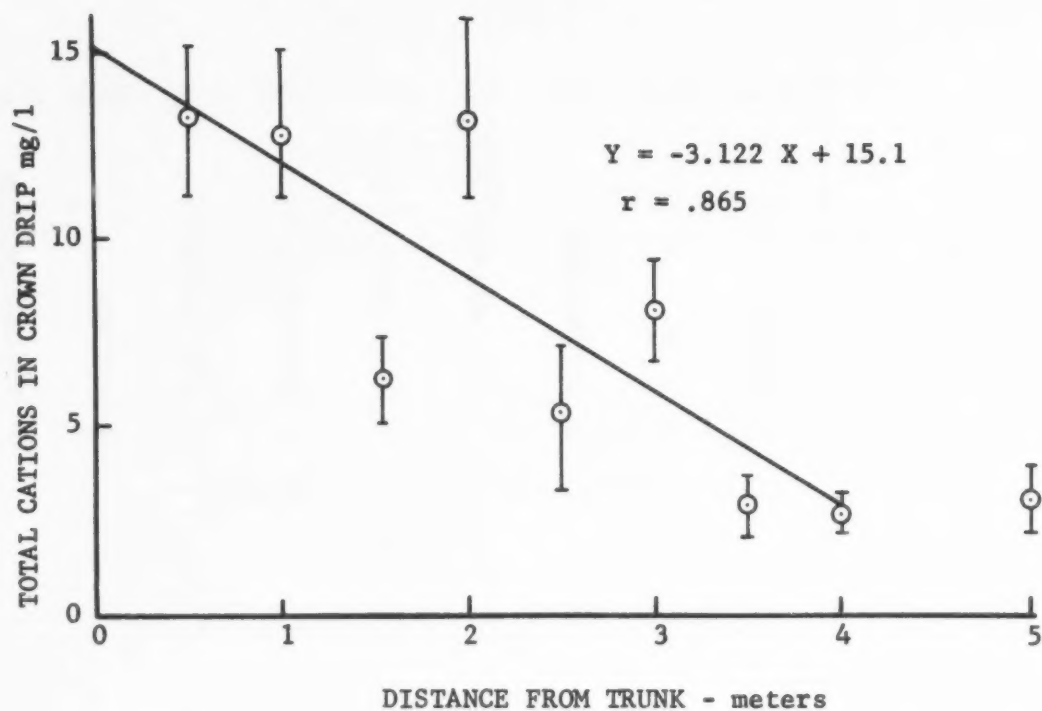


Figure 49. Crown drip cation concentration in relation to distance from ponderosa pine tree trunk.

of total cations in the crown drip is shown in relation to oxidant injury score in Figure 50. The two lowest values do show up on the trees with the most severe impact (injury score 10 and 11) but the others do not show a corresponding relationship.

Effects on Epidemiology of Forest Tree Pathogens

Pathogens have a subtle, but often profound influence on a forest ecosystem. Their activity may affect the rate and even the direction of successional changes (Baxter, 1952; Smith, 1970), the

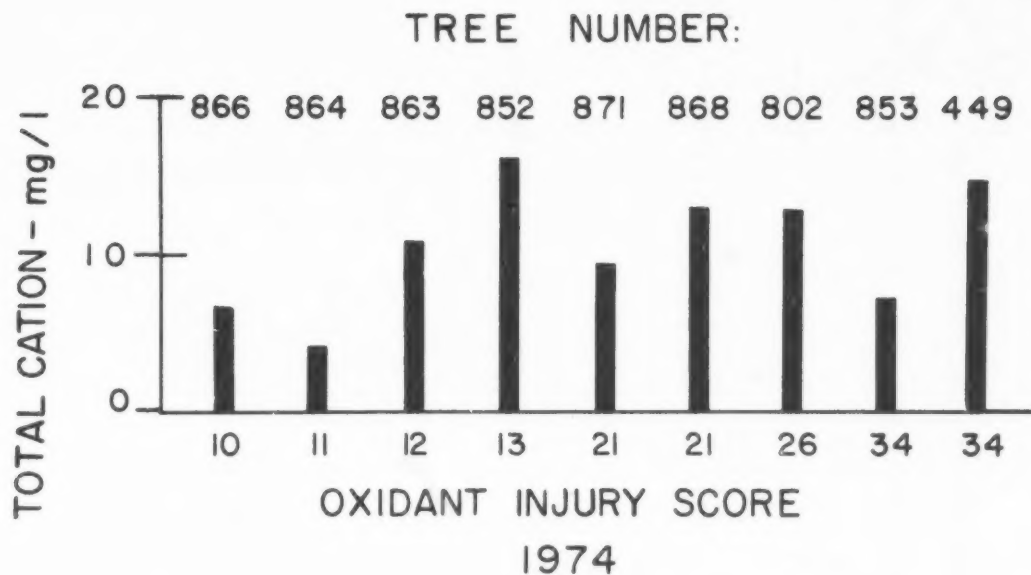


Figure 50. Crown drip cation concentration in relation to oxidant injury score of ponderosa pine.

occurrence of plant species and the overall productivity of the plant community. Thus, fundamental information on the effects of photochemical air pollutants on the activities of forest pathogens is essential in the development of models to predict the long-term effects of pollutants on the forest ecosystem as a whole.

There are many potential pathogens in any forest, including viruses, bacteria, fungi and higher plant parasites, such as the mistletoes (Boyce, 1961). Some may infect the whole plant whereas others may be limited to the foliage, the branches, the stem or the roots. Many pathogens may have little effect upon the forest; others may have a devastating effect. To determine the effects of air pollutants on all forest pathogens is clearly beyond our practical capabilities. Thus,

to limit the scope of the study while developing an initial estimate of the effects of pollutants, we have chosen two approaches.

Objectives ---

General disease survey --- First we are attempting to develop a general overview of the potential effects of air pollutants on disease incidence and severity through a disease survey. All trees on 18 permanent study sites, established across the oxidant air pollutant gradients in the SBNF, are being examined periodically. Each tree has been examined for diseases of the roots, stems, branches and foliage. Rates of increase or decrease in the occurrence of disease will be determined through periodic examinations for the duration of the study. The data will be analyzed to determine the relationship between disease incidence and oxidant air pollutant levels.

Specific pathogen studies --- The second approach involves more intensive studies of selected pathogens, or pathogen types, to determine the effects of oxidant air pollutants on their occurrence and on the various stages of their life history. To date, studies have been initiated on one specific pathogen, Fomes annosus (Fr.) Cke., and on a pathogen-type, damping-off fungi. The selection of these pathogens is based on (a) the known or potential importance of the pathogen in the plant community under investigation, (b) the potential importance of the pathogen in a plant succession model, (c) interactions with other components of the system being studied (see Figure 51), and (d) present knowledge of the pathogen, the facility with which it can be

studied and potential application of the results.

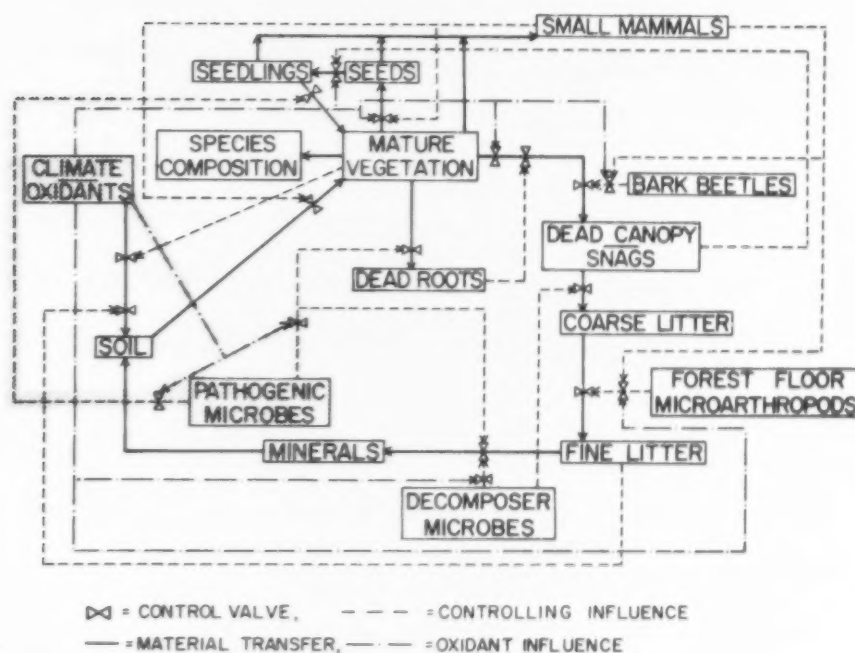


Figure 51. The disease subsystem in the ecosystem.

Root Pathogens ---

F. annosus is usually considered to be one of the most destructive root pathogens in conifer forests of California (Bega and Smith, 1966). Hosts include ponderosa and Jeffrey pine, both of which are adversely affected by oxidant air pollutants. F. annosus has been found to cause damage to these species in the San Bernardino Mountains. However, the effects that oxidant air pollutants may have on susceptibility of ponderosa and Jeffrey pine to infection and colonization by the fungus

are unknown. Also, the ability of the fungus to live, proliferate and cause disease in an environment with oxidant air pollution is unknown.

The following model (Figure 52) indicates areas where oxidant air pollutants probably have direct and indirect effects on disease development by the fungus.

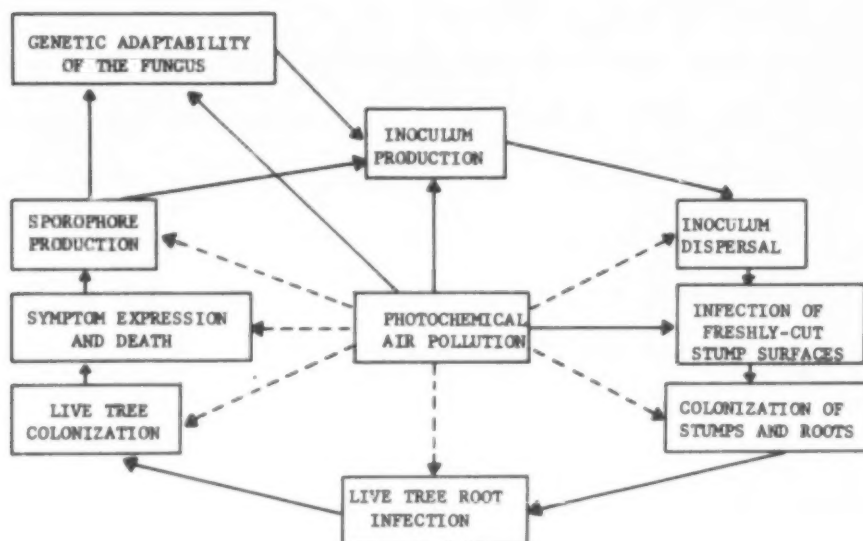


Figure 52. Conceptual model of oxidant effects on the Fomes annosus root disease.

This study was established primarily to determine the effects of pollutants on the life history of F. annosus as outlined above. Field studies were used as much as possible since results would be more applicable to actual conditions in the forest. However, certain controlled environment investigations were necessary to closely monitor ozone concentration and other environmental factors, and to properly

establish cause and effect relationships. The study sites were chosen based on species location and presence of oxidant air pollutant injury. Ponderosa and Jeffrey pine were the two tree species used in the study.

Mature tree susceptibility --- To compare F. annosus susceptibility of existing trees showing severe and light oxidant air pollution injury, inoculation of roots with the fungus was necessary. The 42 trees used in this study were mostly codominant and averaged 38 cm DBH. Two roots of each tree were inoculated and analyzed for infection and colonization at the end of 6 and 12 months. To date, only one root from each tree has been analyzed, Table 11. An analysis of variance indicated no significant differences in infection and colonization by the fungus among trees with different levels of oxidant air pollution injury. Perhaps definite conclusions can be made later when all of the data have been

TABLE 11. INFECTION AND COLONIZATION BY Fomes annosus OF OXIDANT INJURED JEFFREY AND PONDEROSA PINE TREES IN NATURAL STANDS.

<u>Tree Species</u>	<u>Pollution Injury</u>	<u>Infection (%)</u>	<u>Average Colonization (cm)</u>
Jeffrey Pine	None	75.0	27.66
Jeffrey Pine	Slight	71.4	17.44
Jeffrey Pine	Moderate	66.0	17.33
Ponderosa Pine	Slight	71.4	11.34
Ponderosa Pine	Moderate	66.6	13.66
Ponderosa Pine	Severe	60.0	12.23

collected and analyzed.

Tree seedling susceptibility --- A controlled environment experiment was undertaken to determine the susceptibility to F. annosus of ponderosa and Jeffrey pine seedlings fumigated at ozone concentrations of 431.2 and 882.0 $\mu\text{g}/\text{m}^3$. A suitable number of noninoculated and nonfumigated controls were included. Seedlings used in this experiment were grown in activated charcoal filtered greenhouses and therefore were not exposed to ambient air pollutants. The percent of infection of fumigated seedlings was greater than that of nonfumigated seedlings (Table 12). A simple comparison between all ozone and control treatments, showed statistically significant differences in colonization among treatments for ponderosa and Jeffrey pine at the 5 percent and

TABLE 12. INFECTION OF OZONE FUMIGATED AND UNFUMIGATED JEFFREY AND PONDEROSA PINE SEEDLINGS BY Fomes annosus.

<u>Pine Species</u>	<u>No. Seedlings</u>	<u>Fumigation rate (O_3) ($\mu\text{g}/\text{m}^3$)</u>	<u>Infection (%)</u>
Jeffrey	32	0	53.1
Jeffrey	16	431.2 ^a	75.0
Jeffrey	16	882.0	81.0
Ponderosa	32	0	62.0
Ponderosa	16	431.2	81.0
Ponderosa	16	882.0	75.0

^a Seedlings at each concentration were exposed for a period ranging between 58 and 87 days.

25 percent levels respectively.

If the data are considered according to the time of inoculation with respect to length of ozone fumigation, it was found that the rate of colonization of host tissue was also significantly greater at the highest ozone doses.

For example, in the first inoculation schedule, one-third (8) of all seedlings in each of eight fumigation cubicles were inoculated on June 21. Fumigation began several days later and continued until August 23 (58 days) when these seedlings were removed for confirmation of infection and measurement of the invasion of the fungus (cm) above and below the inoculation point. A zero was given when no infection occurred. The total doses were 3.0 and $6.1 \times 10^5 \mu\text{g}/\text{m}^3$ -hr, respectively, and administered at the concentrations of 431 and $882 \mu\text{g}/\text{m}^3$, respectively. Two control groups of 8 seedlings, each which had been maintained in carbon-filtered air in identical cubicles, were removed for evaluation at the same time. An analysis of variance shows that 95 times out of 100 there were no differences in disease development between control and fumigated seedlings as measured by movement of the fungus in root crown tissues. The ozone injury scores at $3.0 \times 10^5 \mu\text{g}/\text{m}^3$ -hrs, determined by the same method as in Figure 32, were 4.0 and 6.3 for ponderosa, 10.6 and 11.1 for Jeffrey pine.

In the second inoculation schedule, eight additional seedlings in each fumigation cubicle were inoculated on August 8, after 37 days of ozone fumigation or filtered air treatment. The fumigation was continued for an additional 50 days at the same concentrations after which seedlings were removed and disease development was determined. The total

ozone doses were 4.5 and $9.2 \times 10^5 \mu\text{g}/\text{m}^3\text{-hr}$. In Table 13, a definite trend toward increased disease development is indicated at the highest ozone dose. The results show that 95 times out of 100 the largest total dose resulted in greater disease development when the combined ponderosa and Jeffrey pine populations from the $9.2 \times 10^5 \mu\text{g}/\text{m}^3\text{-hr}$ dose were compared with one control group using Duncan's multiple range test. The needle injury scores were very similar at both doses and for both species.

TABLE 13. RELATIONSHIP OF CHRONIC OZONE INJURY OF PONDEROSA AND JEFFREY PINE SEEDLINGS TO COLONIZATION OF ROOT CROWN TISSUE BY Fomes annosus.

Treatment	Ponderosa		Ponderosa		Combined
	Average Oxidant Injury Score	Fungus Movement (cm)	Average Oxidant Injury Score	Fungus Movement (cm)	Fungus Movement (cm)
Filtered Air, 1	0	0.3A ^a	0	0.5A	0.4AB
Filtered Air, 2	0	1.3A	0	1.5A	1.4ABC
Ozone, 4.5 ^b	16.9	0.9A	13.3	1.5A	1.2ABC
Ozone, 9.2	17.5	3.4A	14.9	3.4A	3.4BC

^a Values followed by the same capital letters are not significantly different 95 times out of 100.

^b Ozone dose as $\mu\text{g}/\text{m}^3\text{-hr} \times 10^5$.

The eight seedlings remaining in each cubicle were not inoculated. Each tree was observed periodically to compare ozone injury scores with inoculated seedlings but no differences were evident. Unfumigated, uninoculated control plants showed no evidence of foliage injury either.

Although these results cannot be extrapolated to explain disease development in natural stands of larger trees, they did show that ozone treatments cause a higher percentage of infection and a higher rate of colonization of seedlings by F. annosus.

Stump inoculation studies --- F. annosus often spreads to new areas by infecting the surface of freshly-cut stumps. Infection centers are established when the fungus moves from infected stumps to adjacent live trees through root grafts. To investigate this type of infection, 10 ponderosa pine trees in each of two groups, "none" to "slight", or "severe" to "very severe" oxidant injury were cut and their stumps inoculated with a conidial suspension of the fungus. Infection and surface colonization have been determined. All 20 inoculated stumps became infected. However, the 10 stump surfaces from trees severely injured by oxidant air pollution had surfaces colonized 36.9% compared to stump surfaces from lightly injured trees which had 17.6% of their surface colonized. Differences in surface area colonized appear to be real in 95 cases out of 100. Extent of downward and lateral colonization in inoculated stumps will soon be determined. A similar stump inoculation study is planned for Jeffrey pine. These studies should provide an indication of the influence of air pollution on spread of F. annosus by affecting stump susceptibility.

Decay studies --- F. annosus generally causes decay of the wood of infected trees. Thus, studies evaluating the decay capacities of the fungus on wood from air pollution injured trees have been initiated. Wood from ponderosa pine trees, cut for the stump inoculations, was used in a standard soil-block decay test to determine decay rates expressed as weight loss over time. In addition to F. annosus, Poria monticola Murr. and Polyporus versicolor (L.) Fr., two standard decay fungi, were used in this study. Results are not yet available.

Another related experiment is planned which will measure the direct effects of ozone on the decay process of F. annosus. This work will be conducted under controlled environmental conditions in specially designed chambers. This study, plus the soil-block studies mentioned above, should give a good indication of how decay by F. annosus is influenced by air pollutants.

Because F. annosus as well as its hosts, is exposed to air pollutants in the San Bernardino Mountains, studies have been planned to determine the direct effects of ozone on the fungus. Effects on growth, production and germination of reproductive spores, and genetic adaptability of the fungus will be studied. This will entail fumigating fungus cultures in specially constructed growth chambers with various levels of ozone. From such work, it should be possible to determine how well the fungus can survive and maintain its pathogenicity in an air pollution environment.

To determine the influence of air pollutants on F. annosus spread characteristics under natural field conditions, a number of F. annosus infection centers have been located in the San Bernardino Mountains (Figure 1). These have been mapped as to the location and fungal

disease symptom expression. Periodic monitoring over a number of years is planned. Perhaps correlations between such information as rate of pathogen spread and oxidant air pollutant injury to trees can be detected.

Damping-Off Fungi ---

Studies in progress --- We are far from a complete understanding of the so-called healthy forest ecosystem, much less an ecosystem heavily influenced by air pollutants. However, evidence available (Boyce, 1961) indicated that fungi that cause damping-off of very young tree seedlings are found everywhere and probably have an important role in seedling establishment and subsequent stand composition.

Several studies have been initiated in the SBNF to determine what damping-off fungi exist, where they occur, and in what numbers. A soil dilution assay has been initiated in conjunction with a soil microarthropod study being made by participating entomologists. Soil samples for this study are collected periodically during the year adjacent to the entomological samples. Known quantities of soil from the samples are serially diluted and the dilutions placed onto agar media in petri dishes. After a few days incubation, the fungus colonies are characterized and counted. Since both pathogenic and saprophytic fungi are isolated, the fungi are not identified to species or usually even to genus; instead, they are grouped into relative broad classes. The data will provide information on microbial populations, seasonal fluctuations in those populations and possible clues to the effects of air pollutants on soil-borne fungi.

Other studies have been designed to provide information specifically on fungi that cause damping-off. A preliminary bioassay has been made with samples of soil and duff from seven sites. Radish, a host that is highly susceptible to damping-off fungi, was used as the test organism. Direct soil assays for Rhizoctonia spp. and Pythium spp., two common genera of damping-off fungi, have been completed for the seven sites chosen for the first study. To date, Rhizoctonia spp. has not been found on any of the sites, while Pythium spp. has been isolated from Breezy Point and Sky Forest, which have "moderate" to "severe" air pollution injury. These sites were characterized by well-developed soils (Shaver series) beneath mixed conifer stands with ponderosa pines (Section IV - Soils).

Oxidant Effects on Bark Beetle Infestations

Bark beetles are one of the most important groups of forest insects in the United States. Although tree mortality due to these beetles varies considerably from year to year, the fact remains that these insects have tremendous potential for destruction. A breakdown of timber loss due to insects for 1952 showed bark beetles to be responsible for almost 90 per cent of the total saw timber mortality nationally (Graham and Knight, 1965). In California, bark beetles are considered to be the most important forest insect pests. The three most important species are Dendroctonus brevicomis LeConte, the western pine beetle, D. ponderosae Hopkins, the mountain pine beetle, and D. jeffreyi Hopkins, the Jeffrey pine beetle. These beetles, along with the California flat-headed borer, Melanophila californica Van Dyke, and several other bark

beetles were responsible for a loss of 1676 million board feet of timber, or a value of \$23,235,000, in California in 1967*.

These beetles are not necessarily primary attackers except during epidemics. They can usually be considered as secondaries or as symptoms of some other stress experienced by the tree. Stresses that predispose trees to attack by bark beetles such as flooding, drought, lightning strikes, root disease, and photochemical air pollutants. Cobb et al. (1968) discuss the relationship of oxidant injury, as well as other diseases to bark beetle infestations on ponderosa pine. It has been shown previously in the SBNF that as the severity of oxidant injury to ponderosa pine increased, the incidence of western pine beetle and mountain pine beetle infestation increased (Stark et al., 1968). Oxidant injury, therefore, is an important agent predisposing pines to bark beetle attack, and can be considered in the same way as other predisposing agents, such as root disease, drought, flooding, overcrowding, lightning strikes, etc. This was further substantiated by an historical analysis of tree loss in one area, Lake Arrowhead, in the SBNF where there have been substantial increases in tree mortality due to bark beetles since 1951 (Wood, 1971). These previous tree mortality records will be used along with the proposed pest damage inventory to evaluate the overall impact of bark beetles on a forest community stressed by oxidants. The effects of oxidant-weakened trees on the populations of bark beetles or flatheaded borers has not been studied previously. However, a study of western pine beetle infested ponderosa

*California Department of Food and Agriculture, 31 July, 1968

pine at Blodgett Forest in the central Sierra Nevada has shown populations of beetles to be higher in non-diseased trees in all respects (Dahlsten and Rowney, 1974). This was a comparison of trees infected and not infected with the root pathogen, Verticicladiella wagenerii. Results are too preliminary to draw any conclusions as to what this means in terms of tree mortality or to associated organisms, predators and parasitoids.

Detailed studies of the population dynamics of the mountain pine beetle, the Jeffrey pine beetle, and the California flatheaded borer on ponderosa and Jeffrey pines in California have not been done. In addition, population sampling procedures have not been perfected for these species. The western pine beetle, however, has been studied in considerable detail. The early work has been summarized by Miller and Keen (1960). Recent studies have concentrated on the population dynamics of the western pine beetle and the development of population sampling techniques (Dahlsten et al., 1974; DeMars, 1974; Stark and Dahlsten, 1970).

It is obvious that a forest community under stress, for example from high oxidant pollutant levels, will be predisposed to attack by the tree-killing beetle complex. So far, only the trees most sensitive to pollutants have been studied in relation to the beetles that attack them. While the beetles are not the direct cause of the problem, the impact on species and age composition in forest communities can be considerable, as the entire process of change or succession can be hastened due to the activity of beetle populations on ponderosa and Jeffrey pines. The dramatic changes in a plant community due to this

tree mortality has an influence on almost every aspect of the overall study. The removal of certain tree species and the opening of a stand will certainly influence the vegetation that follows. In addition, there will be changes in litter fall, soil moisture and structure, small mammal inhabitants, soil microarthropods, litter decay rates, and regeneration. The rates of change, however, may be ameliorated by the influence of oxidant injured trees on beetle populations. This interaction will have to be characterized in order to model and eventually predict the influence and rates of change in forest communities affected by photochemical oxidant air pollutants.

Objectives ---

The main objectives of this subproject are to characterize the role of tree-killing beetles in stands predisposed by photochemical air pollutants. The relationship of the beetles to other components in the ecosystem is shown in Figure 53. Specific objectives are as follows:

- 1) To determine the degree of susceptibility of oxidant injured ponderosa pine trees to the western pine beetle and the mountain pine beetle, and Jeffrey pine trees to the Jeffrey pine beetle and the California flatheaded borer.
- 2) To investigate the influence of oxidant injured pines on the success and productivity of broods of the four beetle species to be studied.
- 3) To study the direct and indirect influence of photochemical oxidant pollutants on the biology of the four

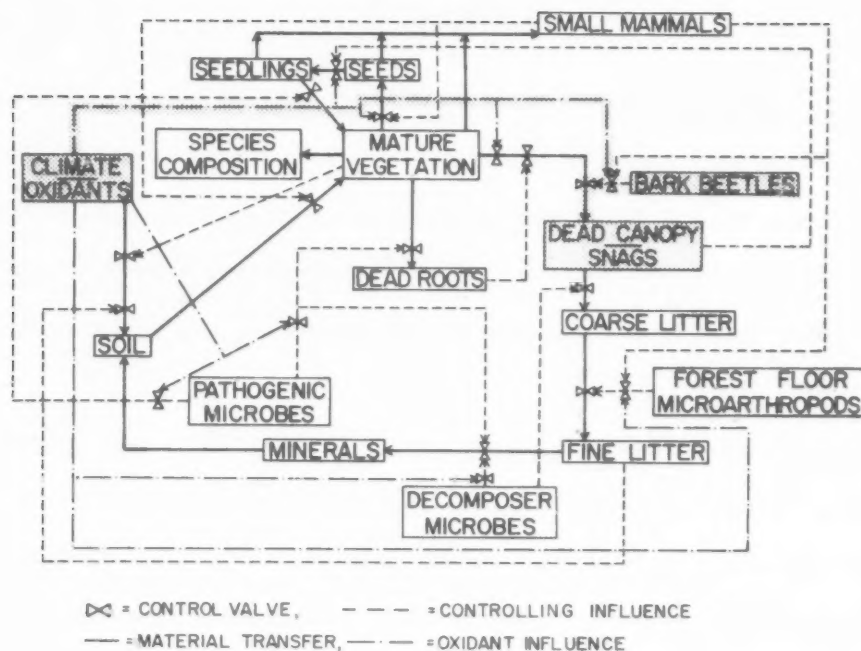


Figure 53. Bark beetle subsystem in the ecosystem.

tree-killing beetles with particular reference to insect associates, parasitoids, and predators.

4) To develop life tables for the four beetles by oxidant injury categories and, based on these tables, to develop predictive models of beetle activity with reference to stand type and pine oxidant injury level.

5) To determine the biological impact and relative importance of each of the beetle species in forest communities and what influence they have on stand change and forest succession.

These objectives have been discussed in other EPA reports (Dahlsten, 1974a, 1974b).

Techniques for Studying Bark Beetles ---

Western pine beetle --- The sampling procedures used in this study have been developed over the past ten years (Stark and Dahlsten, 1970; Dahlsten et al., 1974; and DeMars, 1974 [personal communication]). The details of the sampling procedures including laboratory analytical methods, data forms, and analytical procedures are given by Dahlsten (1974).

The ideal situation is to locate 4 infested trees in each oxidant injury category for each beetle generation. We use three oxidant injury classes as defined by the oxidant injury rating score of Miller (1973b). (See Table 6). Twelve trees are therefore sampled each generation, Figure 1. Trees are often green and have not faded, so beetle-produced frass (boring dust) or pitch tubes are used to find infested trees. Local personnel of the State Division of Forestry and the U.S. Forest Service aid in the search for trees. Once trees are found, they are given an oxidant injury rating, and other statistics such as height and diameter are recorded. Trees with mixed broods (more than one species of bark beetle present) are not selected. The mountain pine beetle and the western pine beetle are commonly found infesting the same tree.

The various sampling procedures, the data form identification, and the types of information recorded are diagrammed (Figure 54). The basic sampling unit consists of paired 88 cm² discs that are cut with a gasoline powered Drillgine saw. Samples are taken at 1.5 m intervals along the length of the infestation. The following is a summary of the four techniques used:

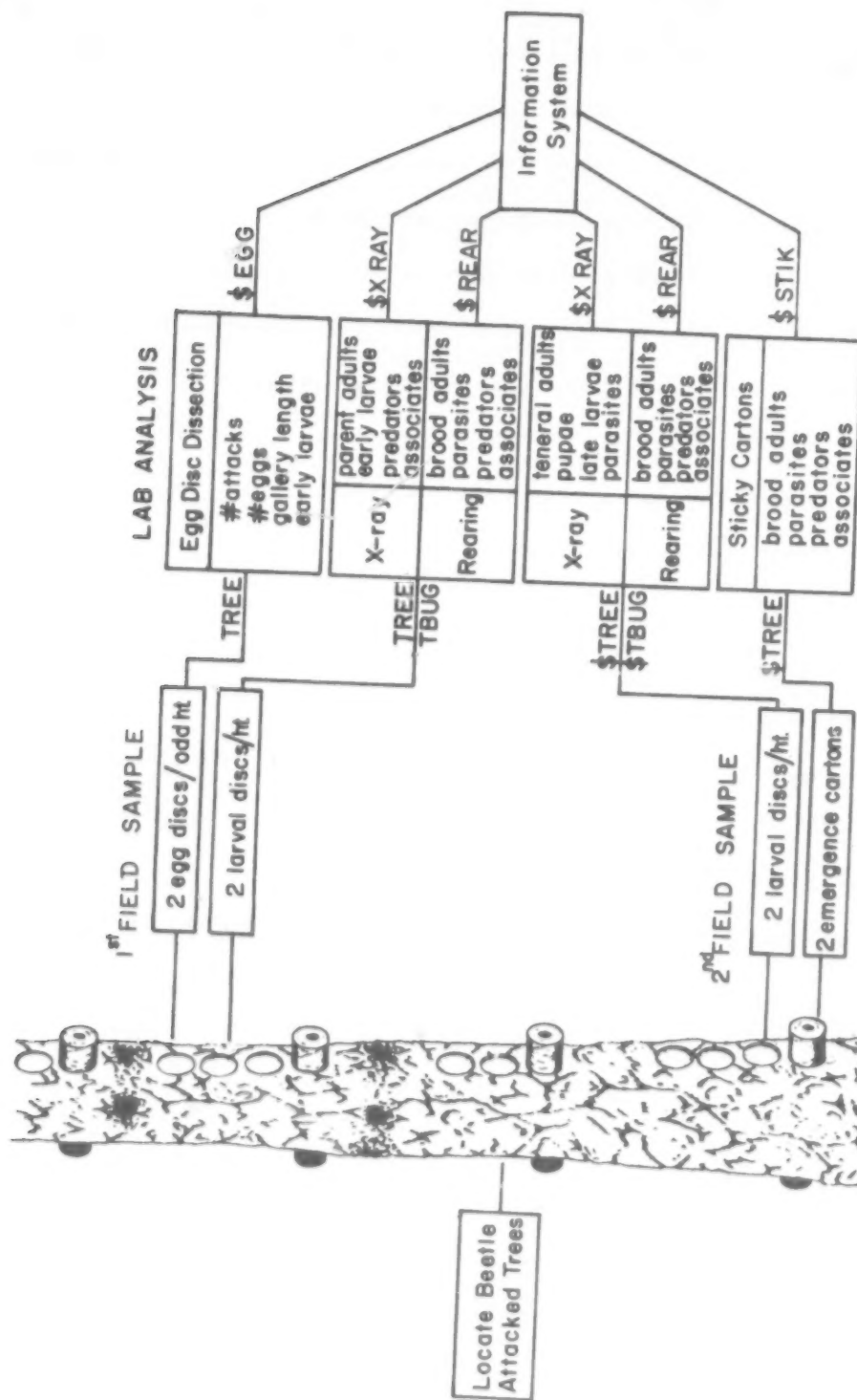


Figure 54. Graphic summary of the population sampling procedures used for the western pine beetle, showing data sets and the type of information included for the San Bernardino study.

1) Egg Discs - Paired are cut at 3.0 m intervals. (It is not necessary to take these discs at 1.5 m intervals, so every other one is skipped.) These discs are taken only once per generation and are used to evaluation attacks, egg density, and egg mortality.

2) X-ray Discs - Paired discs are cut at 1.5 m intervals, are returned to the laboratory and x-rayed, then they are placed in rearing cartons. During the first generation, the discs are cut twice, the first time when the beetles have reached, at most, the third instar of larval development and the second time just prior to, or immediately after, pupation. The second generation is treated differently since the population overwinters in this generation. Discs are taken three times, once at the third instar stage and then once before winter and then again after winter in the spring of the following year. The developed x-rays are interpreted for beetle stage, parasitoids, predators, and miscellaneous insects. The abundance of each of these inclusion types is recorded.

3) Rearing - Each x-ray disc is placed in a separate ice cream container with a vial attached and placed through the lid. All insects are reared from the bark discs, collected and identified. Approximately 75 species are reared from these samples. The discs are kept in rearing nine to twelve months.

4) Sticky carton - Ice cream containers with a sticky substance placed on the interior to prevent insects from voring out are placed on trees in pairs at 1.5 m intervals at the time that the last x-ray discs are taken. These cartons cover an area of 88 cm². Cartons are put up once during the first generation and are removed for analysis only after

it is determined that all insects have emerged from the study trees. Cartons are put up and removed twice in the second generation, once before and once after winter. The sticky cartons are used as a comparison to the laboratory reared samples since rearing conditions influence the western pine beetle as well as a number of the other insects associated with the western pine beetle.

All of the information is punched onto cards, and programs for data capture, summarization, and analyses have been written for each data type.

Mountain pine beetle and Jeffrey pine beetle --- Studies on these two beetles were initiated in 1974 to develop sampling procedures and to rear and identify associated insect species.

Infested trees in which broods had completed development were selected whenever possible. Mixed broods were avoided, but often bark beetles (Ips spp.) or the California flatheaded borer were found in portions of the sample trees. Six D. jeffreyi infested Jeffrey pines from the Big Bear and Heart Bar areas and five D. ponderosae infested ponderosa pines from the Lake Arrowhead area were used for the determination of sample size. Bolts were taken from one tree of each species for rearing. Sample bolts were taken from the top, mid and bottom of each infested pine species. Broods in both trees were in the late pupal stage, and all rearing was done outside at Lake Arrowhead. Emerging insects were trapped in KAAD (a preservative for insects) and collections made on a weekly basis from 26 July through 14 November, 1974.

Each tree to be sampled was felled, examined for mixed broods, and measured for standard tree and infestation characteristics. Paired samples

were taken from points 1.5 m above the base of infestation, 1.5 m below the top of the infestation, and from the mid-point between these two. The samples were sections of bark 60 cm long by one half the circumference of the bole.

Laboratory analysis of each sample consisted of placement of an acetate overlay upon which five nested samples (rectangles of 1000 cm², 500 cm², 250 cm², 100 cm² and a circle 100 cm²) were drawn. Parameters measured included: number of attacks, adult gallery length, number of larval mines, pupal cells, emergence holes, and in some cases the number of egg niches and Coeloides (a parasitoid) cocoons.

Preliminary Analyses of Bark Beetle Populations ---

Western pine beetle --- All of the information from the two generations in 1973 has been captured, and the same is true for the two generations in 1974 except that the rearings are still in progress. Considerable effort has been expended to develop and debug computer programs, and to summarize and analyze all of the completed data sets, but to date, only the egg disc information has been partially completed. Statistical analyses of these data is incomplete.

The trends indicated by the egg data, however, are encouraging. Other interesting influences of oxidant air pollutants on other aspects of western pine beetle biology are anticipated. Since populations of the western pine beetle have been studied for the past ten years at Blodgett Experimental Forest (Stark and Dahlsten, 1970; Dahlsten et al., 1974), there is a base of information available to compare with the SBNF populations. These comparisons will be interesting as

many of the ponderosa pines at Blodgett have been stressed by a root pathogen, Verticicladiella wagnerii, but there is little, if any, oxidant air pollutant injury to the trees.

In the SBNF, the mean attack rates of the beetles were highest in the first generation in both years (Table 14). A similar trend was noted at Blodgett Forest, but the differences are greatly exaggerated in the SBNF. The mean attack rates in the first generation of 1973, hereafter referred to as 1973-1, were higher (2.57 and 2.49/sample disc) than any of the previously recorded highs at Blodgett (1.82/sample disc). Not enough generations have been studied to explain this.

Mean attack rates were more variable in the SBNF, and this may be an effect of air pollutants on the trees. Attack rates tended to be higher in the Class III trees (slight to no visible symptoms) except in the 1973-1 generation. However, if that generation was part of an epidemic outbreak, this could explain the breakdown of any behavior pattern. For example, vigorous trees, or trees that have not been predisposed by some other factor, are often killed by beetles during epidemic outbreaks.

Another valuable attribute for evaluating bark beetle populations (Objective 2) is the mean number of eggs per centimeter of gallery length. Results were extremely variable, and no consistent trend could be found (Table 14). The values tended to be higher in the second generation in both years. A similar trend was noted at Blodgett (Dahlsten et al., 1974). Again the data from the SBNF is much more variable than that from Blodgett. The values from five second generations at Blodgett ranged from 1.46 to 1.94 eggs/cm gallery length and

TABLE 14. WESTERN PINE BEETLE EGG DISSECTION DATA GROUPED BY GENERATION AND OXIDANT INJURY CLASS^a, EPA, SAN BERNARDINO AIR POLLUTANT STUDY, 1973-74.

No. Samples or Means	1973						1974					
	1st. Generation		2nd. Generation		1st. Generation		1st. Generation		2nd Generation		1st. Generation	
Oxidant Injury Class	I	II	III	I	II	III	I	II	III	I	II	III
No. Trees	0	8	4	6	4	2	5	7	0	10	2	0
No. Discs	0	88	44	60	36	20	48	98	0	104	13	0
Discs with galleries	0	82	43	57	34	19	46	95	0	92	13	0
Attacks/disc with galleries	0	2.57	2.49	0.78	0.89	1.69	1.84	2.23	0	0.87	0.89	0
Mean Gallery length (cm)/disc with galleries	0	69.80	71.48	37.46	36.97	40.18	63.04	47.45	0	32.27	35.65	0
Mean No. eggs/disc with galleries	0	63.70	60.76	31.83	43.46	37.54	41.70	54.55	0	43.77	51.25	0
Mean No. eggs/cm gallery	0	0.89	0.88	0.85	1.17	0.90	0.66	0.82	0	1.37	1.10	0
Mean % hatched eggs	0	85.18	80.73	68.92	70.46	67.12	84.80	83.39	0	71.90	45.20	0

^a Trees classed according to oxidant injury rating score (Miller, 1973b; i.e.,

Class I Score 1-14 - Very severe to severe injury

Class II Score 15-28 - Moderate to slight injury

Class III Score 29+ - Very slight to no visible symptoms of injury).

for four first generations from 1.32 to 1.54. Values consistently less than 1.0 were recorded in the SBNF (Table 14). The highest value, 1.37, was recorded on severely injured trees in 1974-2 generation, but results from other generations were too variable to draw any conclusions.

The percentage of hatched eggs per sample disc can often be used as an index of egg mortality which is essential for estimates of brood productivity (Objective 2) and for the development of meaningful life tables (Objective 4). The egg discs can and must be taken well after oviposition takes place to insure that all eclosion (hatching) has occurred. The estimates of egg mortality at Blodgett vary between 15 and 25 percent. Again the data from the SBNF are more variable (Table 14). There was a tendency for the percentage of eggs hatched to be lower in the less severely injured trees. Since the percentage of eggs hatched is used as an indicator of egg mortality there is a suggestion that oxidant injured trees increase egg mortality primarily or secondarily. Work on this facet of the egg data will be expanded in the future (Objective 3).

Future work will concentrate on all the possible influences of oxidant air pollutants on beetle populations in addition to analyses by tree height and beetle generation. Initial comparison with data from Blodgett Forest indicate that the interaction of oxidant injured trees with western pine beetle populations is unique and that oxidants may affect the beetles more directly than previously thought.

Mountain pine beetle and Jeffrey pine beetle --- Sampling procedures were not available for either the mountain pine beetle or the Jeffrey pine

beetle. The first step was to determine sample size. Preliminary summaries and statistics for number of attacks and gallery length have been completed for both species (Appendix J and K). The results have not been analyzed statistically, but the data suggest a 500 cm² rectangle would be suitable.

Counts of larval mines and pupal cells of D. jeffreyi were complicated by the feeding of the California flatheaded borer which was present to varying degrees in all samples. Estimates of the proportion of the host sample utilized by the flathead larvae were recorded and will be used to evaluate interspecific competition. Field observations indicate that the flatheaded borer may be an important component in the forest communities of southern California, particularly in Jeffrey pine.

Mountain pine beetle trees were also difficult to locate and usually the broods were mixed with those of the western pine beetle. There was evidence that ponderosa pines had been killed by the mountain pine beetle but currently infested trees were rarely located in 1974. This suggests an important interaction with western pine beetle populations. However, it appears that the most important factors in terms of extensive pine mortality are the western pine beetle and the flat-headed borer, and further studies should concentrate on the above named beetles, not the mountain pine beetle or the Jeffrey pine beetle.

All of the insects reared from the sample bolts to determine the associates of the mountain pine beetle and the Jeffrey pine beetle have been preserved, identified, and counted (Appendix L and M). Future analyses of rearings for both species will include the distributions of each insect through time and by height. A knowledge of the

associate complex for each species is necessary for evaluation of the effects of oxidant injured pines on beetle populations either directly or indirectly through the effects of parasitoids, predators, and competitors. The species lists compiled thus far are consistent with the present knowledge of bark beetle associate complexes (Dahlsten, 1971; Dahlsten and Stephen, 1974), and there were no unusual discoveries.

Oxidant Effect on Pine Needle Litter Production on the Forest Floor

As a result of injury to vegetation due to oxidant air pollutant effects, reduction in tree growth, soil moisture stress, pathogenic effects, and bark beetle interactions, as discussed in the previous sections, dead organic matter accumulates on the forest floor in the form of needle litter and coarse woody fragments. The degree to which this accumulation is occurring in the various forest ecosystems under study is being investigated.

Litter fall was collected on screens (Figure 46) of 0.209 m² area (18 inches square) in the fall of 1973 (6 trees) and of 1974 (39 trees), with oxidant injury ratings ranging from 3 (severe injury) to 33 (slight injury) in 1973, and from 9 (severe injury) to 44 (no injury) in 1974. Needles were separated from other litter, and the mass per fascicle of needles was determined to obtain a measure of the size of the needles in the litter fall. Total needle and other litter were also measured. Needle-fall from selected trees (1973) have been analysed for their content of nitrogen, phosphorus, potassium, calcium and magnesium, and will be analysed for the same elements in 1974 also.

The organic forest floor was sampled with a core-cutter at 110

sites under 52 pine trees variously affected by oxidant air pollutants, and the mass per unit area was related to thickness. Using these data and transect measurements of thickness on 12 major plots, the total amount of litter on the forest floor was estimated. The forest floor was also measured in radial lines from the trunks of somewhat isolated individual pine trees and the pattern of needle litter accumulation on the forest floor was determined.

Rates of Pine Needle Litter Accumulation and Oxidant Injury ---

One of the most obvious effects of air pollutants on the ponderosa and Jeffrey pine trees is the decrease in size and number of needles on the tree. It is clear that as the injury to the tree increases, the older needles fall from the tree increasing the litter-fall, until most of the older needles are on the ground, and the production of new needles is low. The mass of needles collected on screens placed under the pine trees from September 10 to December 11, 1974, the period of normal needle-fall with minimal effect of snow breakage of the tree, is shown for the Lake Arrowhead region (Camp Paivika to Camp O-Ongo) in relation to the oxidant injury scores for the individual trees in Figure 55.

The oxidant injury scores determined by another subproject for these trees ranged from 9 (severe impact) to 34 (very slight impact). It can readily be seen that needle-fall was low in the relatively healthy trees (oxidant injury score 25), but as the injury becomes increasingly severe, needle-fall increases to a maximum where the average injury score is about 15 and drops again to low values in the

severely injured range (oxidant injury score 9 and 10). Trees with "severe" injury retain only the current and previous year's needles, and the needles are relatively short in length. The variation in litter caught on the screens was quite large under those trees with oxidant injury scores ranging from 16 to 21, but otherwise the data appear to represent significant changes with time.

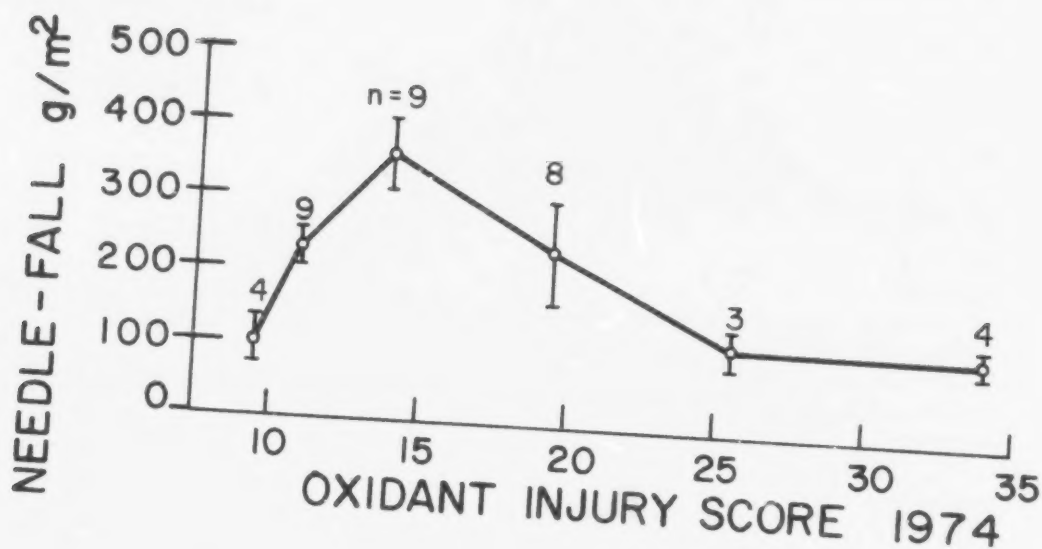


Figure 55. Mass of Ponderosa pine needle litter-fall compared to oxidant injury score, 1974; for Camp Paivika plot to Camp O-Ongo plot.

The oxidant air pollutants also affect the size of the needles in the needle-drop collected. The length, or more properly the average

mass per cluster of 3 needles (fascicle), is shown in Figure 56 in relation to the oxidant injury score. The decreased mass as the impact grows more severe is clearly shown and is highly significant. Each point on Figure 56 represents a single tree.

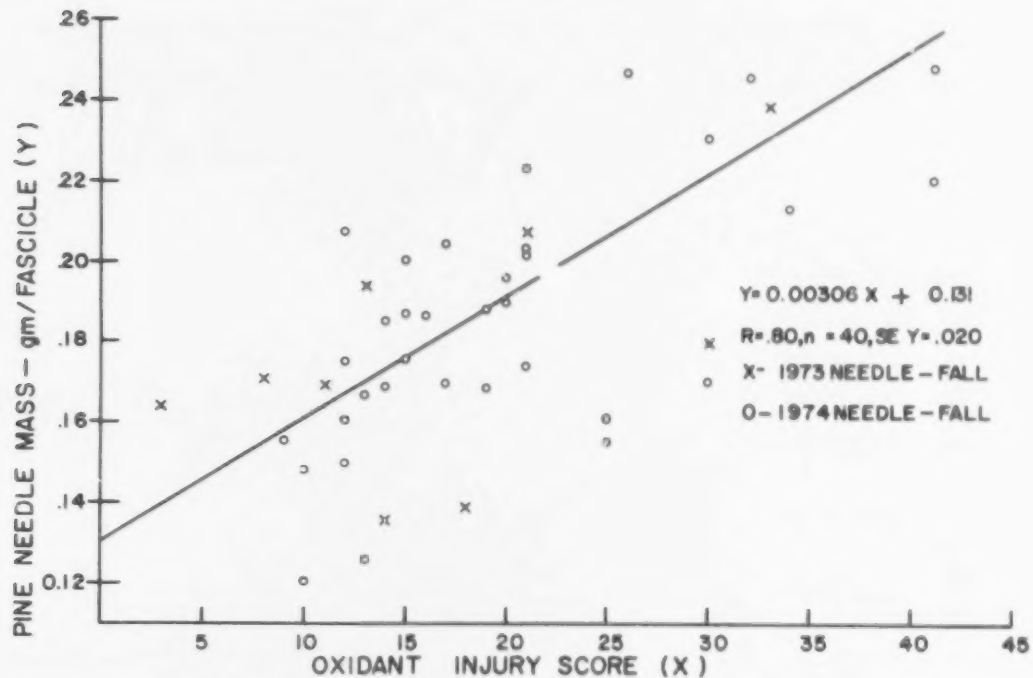


Figure 56. Ponderosa and Jeffrey pine needle-fall compared to oxidant injury score, Sept. - Dec., 1973 and 1974.

Nutrient Content of Needle-Fall ---

Analysis of the needles which fell from the pine trees in 1974 is currently in progress, however, preliminary analysis of needles from 5 selected trees in 1973 has been completed and the results shown in Table 15.

The evidence for an effect of air pollutants on nutrient content of the needle-fall is inconclusive, but it appears that the severely affected trees with oxidant injury scores of 3 to 11 are higher in

TABLE 15. CONTENT OF NUTRIENT ELEMENTS IN NEEDLE FALL COLLECTED IN
AUTUMN 1973

Plot	Tree No.	Oxidant Injury Score	P	K	Ca (g/100 g)	Mg	N	C
COO	Al-449	33	0.044	0.199	0.357	0.123	0.426	53.0
UCC	Al-448	21	0.050	0.246	0.417	0.141	0.403	53.2
COO	Go-863	11	0.066	0.336	0.355	0.103	0.444	52.1
SF	Go-1244	8	0.056	0.285	0.363	0.155	0.670	54.2
UCC	Al-405	3	0.048	0.242	0.173	0.079	0.532	52.6

nitrogen (N) content than those less affected (oxidant injury scores 21, 33). Analyses from the 1974 samples should be more definitive.

PROCESSES IN ECOSYSTEMS -- IMPACTS ON LITTER DECOMPOSITION

The continuation of ecosystems depends upon natural recycling of the dead organic material which accumulates within them. Coarse woody fragments, as well as fine needle litter must be broken down in several stages in decomposition. Soil microarthropods, and various fungi work to break down the accumulated litter.

Effects on Major Decay Fungi of Woody Litter

Trees chronically exposed to oxidant pollutants lose photosynthetic capacity; one possible effect may be an alteration of woody tissues and a change in the resistance of the wood to attack by decay fungi. Such altered resistance may affect litter accumulation and

nutrient cycling, in addition to various other effects on the forest floor. On the other hand, direct exposure of decay fungi on the forest floor to air pollutants may alter their rate of growth or ability to decay wood which would produce similar effects on litter accumulation and nutrient cycling. Collection sites for this subproject were coordinated with other projects dealing with the soil, the litter and associated fungi and insects. The objective of this study as indicated in a general way in Figure 57, is to answer the question of whether exposure to air pollutants alters wood decay resistance or the activity of decay fungi.

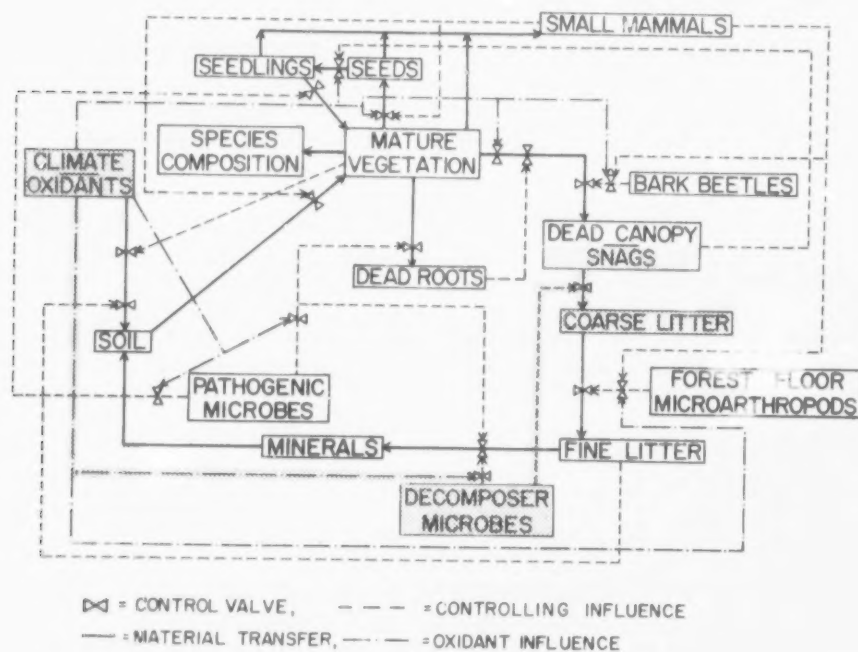


Figure 57. Woody litter decay subsystem.

Identification of the Kinds of Fungus Decomposers of Woody Litter ---

Pieces of large ponderosa pine wood lying on the ground were collected during three seasons of the year from sites representing the full range of long-term oxidant exposures. Isolates were screened for ability to cause weight loss in wood by exposing wood blocks to actively growing agar cultures (Figure 58). Decay resistance and rate of decay are being measured by a standard soil-block method (American Society for Testing and Materials, 1973). For the most active decayers of the fungi isolated, decay rate and hyphal growth rate will be measured in the laboratory under conditions of high and low ozone concentration.

Collection of wood sample material for decay resistance testing is completed; the test for decay resistance was initiated in December 1974. The isolation of decay fungi through three seasons of one year is completed. Screening for the ability to decay wood is continuing. Although popular usage differs, we prefer to reserve the term "decay" for wood destruction due to *radiomycete* fungi, whether they are white rotters or brown rotters. This leaves soft-rot fungi, mold fungi, blue-stain fungi and wood-inhabiting bacteria as wood-destroying microorganisms which do not produce "decay". Despite the fact that none of the isolates has as yet been identified, 11 of the fungi have been shown by general screening to be wood destroying organisms, and microscopical examination has certified that at least five definitely are decay fungi. Superficial examination of the decay suggests that all wood destroying isolates may be white-rot fungi. This is a surprising finding since most decomposers of coniferous wood in soil contact are brown-rot fungi.

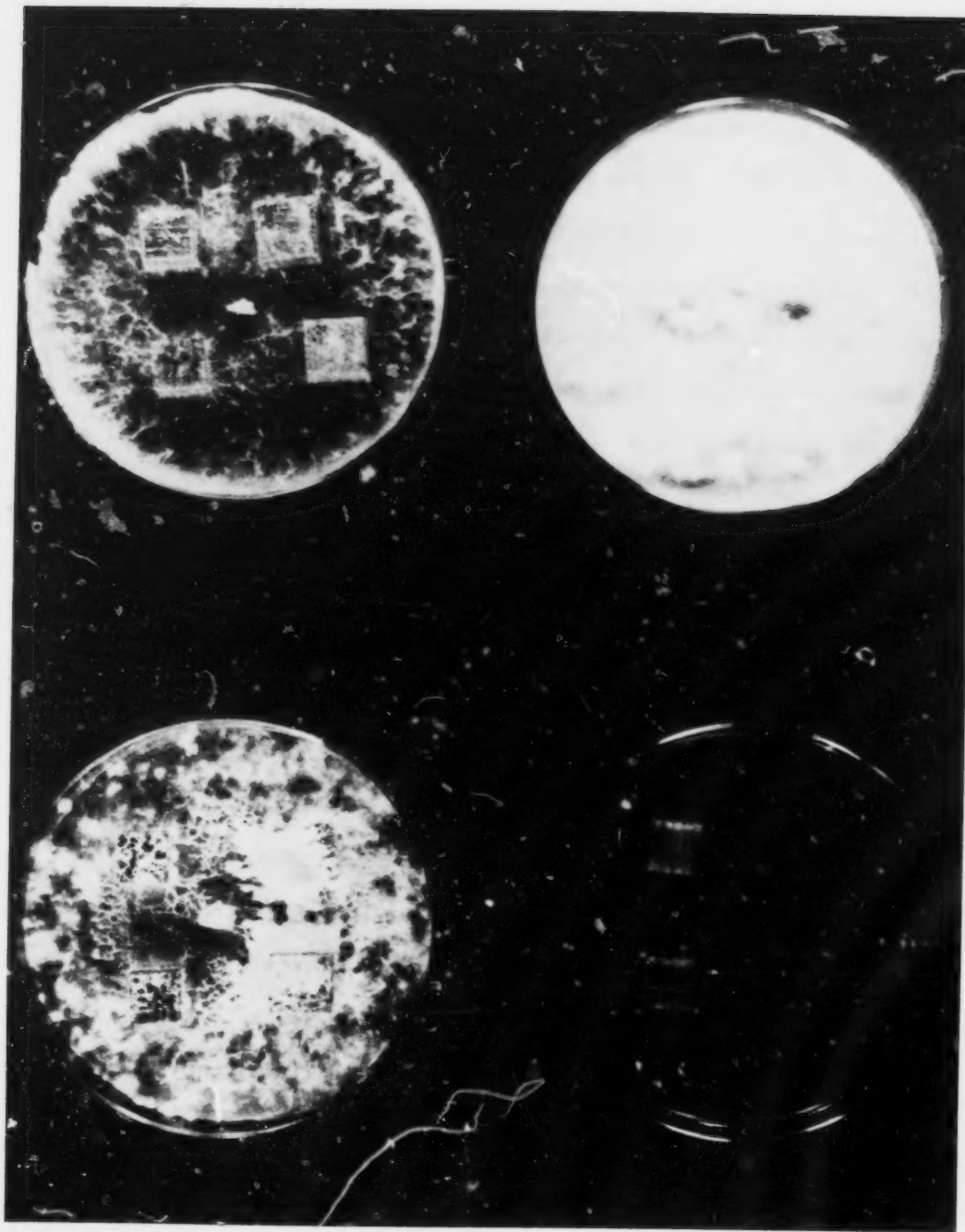


Figure 58. Agar-block screening test for establishing ability of fungi to decay wood, showing a range in fungal ability to invade wood blocks.

The analysis of decay and growth rate under laboratory exposure to ozone will be initiated during the coming year.

Effects on Microarthropods in Forest Litter and Soil

Litter microarthropods form an important, if rather inconspicuous, component of the forest ecosystem, and it is therefore necessary to evaluate the effects of potentially disruptive environmental contaminants, such as oxidant air pollutants, on these abundant arthropods. The pine needles, twigs, and other organic materials that make up the forest floor and the underlying upper layers of the mineral soil contain a complex and diverse community of small (often less than 2-3 millimeters) animals belonging to the phylum Arthropoda, which includes insects, mites, spiders, centipedes and a variety of other less well known animals which, taken together, can be termed "litter microarthropods." Litter microarthropods can occur in very large numbers, with population estimates in pine forest soils ranging from 102,000/m² in Tennessee, (Crossley and Bohnsack, 1960), to 200,739/m² in California (Price, 1973).

The primary role of litter and soil microarthropods, as shown in Figure 59, in conjunction with the soil microflora (fungi, actinomycetes, and bacteria) is to decompose and reduce the organic residues, both plant and animal, which fall to the forest floor (Edwards et al. 1970; Millar, 1974). They can contribute directly to the decomposition process by mechanically breaking down these organic materials, such as pine needles, into smaller fragments. The activity and movements of the microarthropods helps to further reduce these fragments

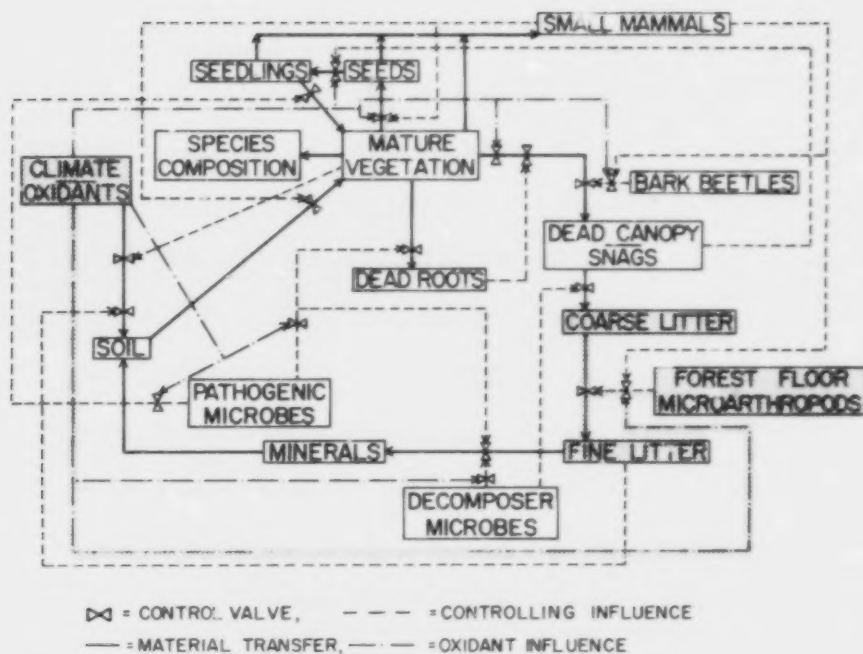


Figure 59. Litter microarthropod decomposer subsystem.

into humic substances and then mix these and other breakdown products with the mineral soil below. These processes make the nutrients, which are contained in the undecomposed organic material, available for utilization by other plants and animals in the ecosystem. Furthermore, these disintegrating and reducing activities can increase the surface area of organic material and create microhabitats and substrates that are more easily attacked by the soil fungi and bacteria. These microflora in turn chemically decompose and change the organic residues which benefits the microarthropods. Thus, both directly and indirectly, through decomposition and mechanical mixing and with complex interactions with

soil microflora, soil microarthropods affect overall soil fertility and nutrient cycling.

At the same time, species composition and abundance of litter microarthropods can be influenced by the various soil and litter properties such as the quantity and quality of the organic litter, its rate of accumulation, soil water availability and the pH of the soil. Litter microarthropods are also affected by the biological components of the soil, including the soil microflora. Chemicals released by the action of the soil fungi may inhibit or enhance litter microarthropods and some of these arthropods feed on, and hence are dependent on, certain fungi. From a long-term standpoint, these complex feedback interrelationships between litter microarthropods and the physical and biological attributes of the soil can significantly affect forest succession through natural seed bed preparation, seed germination success and seedling survival as well as the basic role of decomposition.

Consequently, any disruption which affects, directly or indirectly, the microfauna and flora can potentially affect the entire ecosystem. Long-term implications of such an ecological imbalance have particular significance for a forest ecosystem, in contrast to a typical agroecosystem since it depends almost entirely on natural processes for maintenance of fertility and recycling of nutrients, rather than artificial inputs such as energy dependent fertilizers.

Stable forest ecosystems are generally considered to have a relatively constant rate of litter production (Burgess, 1967), and any factor that could potentially affect this balance warrants investigation. This disturbance could involve not only change in the rate and amount of lit-

ter fall but also the quality of the organic matter itself and other factors, such as the composition and amounts of dissolved organic matter in the rain water passing through the canopy. These changes could take several years as ponderosa or Jeffrey pine gradually became weaker due to continued exposure to oxidants or could be accelerated by disease or bark beetles or an interaction of factors. Ultimately, under natural conditions, the dead trees themselves fall to the forest floor and are decomposed.

The response of the litter microarthropods and other components of the forest floor to these changed conditions can influence the nature of forest regeneration through nutrient availability. The overall objective, then, of this study is to determine the effects, primarily indirect, of photochemical air pollution on the litter microarthropod component of the ecosystem and to evaluate the effect of this component on the other elements of the system.

Objectives ---

1. Determine species abundance and diversity in the forest floor under selected individual trees.
2. Relate these population characteristics to soil and litter properties.
3. Determine how photochemical air pollutants influence litter microarthropod populations: a) through their effect on litter quantity and quality, and b) through their effect on microbial activity.
4. Relate litter microarthropod populations with soil microbial

populations under selected individual trees: a) by correlating microarthropod and microbial species composition and relative densities, b) by determining the succession of soil microarthropods and microflora in the decomposition of forest litter and their effect on gross decomposition rates.

5. Determine and compare characteristics of ecological disruptions of litter microarthropods caused by oxidant air pollutants with undisturbed (natural) sites and with disruptions caused by other factors, i.e., pesticides, fire, and logging.

6. Identify specific components of the litter microarthropod community as indicators of an ecosystem disrupted by oxidant air pollutants.

Identification of Microarthropod Decomposers ---

The plots and individual sample trees were selected primarily on the basis of oxidant injury ratings in an attempt to compare plots and individual trees with different oxidant levels. An attempt, largely unsuccessful, was made to choose isolated undisturbed (other than by oxidant air pollutants) trees relatively uninfluenced by adjacent trees to minimize possible sources of variation. In addition, an effort was made to work with trees, at least within plot, that were of similar size and age class.

Sampling --- Samples were taken with a rectangular shaped soil corer, 32.26 cm² (5 sq. in.) in area. Samples were taken at six week intervals, with some variation in time due to snow and weather conditions. Ten cores per tree are taken on each sample date and

where appropriate, the different forest floor layers (litter, fermentation, humus) and the top 0-5 cm of mineral soil were measured and stored separately for individual extraction. The forest floor beneath each sample tree was divided into eight quadrants based on cardinal direction, the exact dimensions of which depend on crown size, ground cover and disturbances of the forest floor. Samples were taken by randomly selecting the quadrant and specific direction from the tree bole, and the location of each individual core was mapped as precisely as possible using the angle (from N, 0-360°) and the distance from the bole. (This sampling is directly coordinated with the Litter Decomposition and Nutrient Cycling subproject.)

Extraction --- All cores taken in the field were stored at low temperatures until extraction. The microarthropods were extracted from the soil using a high heat gradient modified Berlese funnel system (Price, 1973). This system uses a combination of heat, light and drying action on the individual soil samples to drive the microarthropods from the soil core through steep walled plastic funnels sprayed with a dry silicone lubricant into alcohol filled vials where they are preserved for later analysis and counting. The temperature in the funnel units was controlled by a voltage regulator and increased gradually from an initial temperature of 32°C in order to avoid excessively rapid heating and drying of the soil cores which could result in microarthropods being killed in place, rather than being driven into the alcohol vial. Each core was extracted in the system for a minimum of three days.

Data Processing and Analysis ---

Different data set types have been developed for this subproject - Forest Floor Depth Data (FFDD) and Soil Microarthropod Data (SBUG). The initial data analysis routines will be able to yield basic statistics on various soil microarthropod taxonomic and functional groups combined according to horizon and date.

Litter Microarthropods Under Trees Differing in Oxidant Injury ---

A preliminary list of specimens collected during the initial phases of the study is given in Appendix N. The systematics of many of these groups, especially the Acarina, are poorly understood, and at this point many groups have not been identified beyond their family level.

Since the data could only be summarized for the first three sample dates in 1973 (August 16; October 4; November 27), the results can only be considered as preliminary and are presented to show trends. The data are from three of the six plots presently being used (Snow Valley (SV), N. E. Green Valley (NEGV), and Breezy Point (BP)).

Table 16 gives comparisons for selected taxonomic groupings between the plots with different oxidant air pollutant injury ratings: SV (16) and BP (21) being "moderate" and NEGV (33) having "very slight" injury. The results are consistent with the least injured plot, NEGV, averaging more total microarthropods than the two "moderate" plots on each sample date. The sample at BP taken initially on 27 November, 1973, was intermediate in total microarthropod density.

These results must be considered in light of individual tree variation (Table 17). With the exception of BP, where the "healthy" #394 had

TABLE 16. MEAN NUMBER OF MICROARTHROPODS IN SELECTED TAXONOMIC GROUPINGS IN LITTER SAMPLES FROM BENEATH TWO TREES AT THREE MAJOR PLOTS, NE GREEN VALLEY (NEGV), SNOW VALLEY (SV), AND BREEZY POINT (BP).

Plot	(10 SAMPLES PER TREE)							
	NEGV (Very Slight)			SV (Moderate)			BP (Moderate)	
	Aug. 16	Oct. 4	Nov. 27	Aug. 16	Oct. 4	Nov. 27	Nov. 27	
1973 Oxidant injury								
Collection dates								
Total Cryptostigmatid adults	20.5	20.3	28.7	13.2	6.2	24.8		34.3
Total Cryptostigmatid immatures	11.6	11.2	7.4	7.7	3.0	2.9		4.4
Prostigmatid adults	23.6	26.9	54.6	12.6	41.7	17.3		9.7
Miscellaneous								
Prostigmatids	36.2	52.4	12.2	24.6	7.7	12.5		20.6
Total Prostigmatids	60.0	79.3	66.8	37.5	49.3	29.8		30.2
Total Insects	4.4	3.4	14.1	9.0	2.3	9.9		29.1
Total Microarthropods	156.3	193.5	183.8	104.6	110.2	97.2		128.1

TABLE 17. MEAN NUMBER OF TOTAL MICROARTHROPODS UNDER INDIVIDUAL TREES OF DIFFERENT OXIDANT INJURY AT NORTHEAST GREEN VALLEY (NEGV), SNOW VALLEY (SV), AND BREEZY POINT (BP), 1973.

Plot No.	Tree No.	Oxidant Injury Score	Total Cryptostigmids		Prostigmids		Mesostigmids		Total Insects	Others	Total Microarthropods
			Adult/Immature	Adult/Misc./Total	Adult/Misc./Total	Adult/Immature	Adult/Immature				
16 AUGUST											
NEGV	614	24	32.0	14.2	17.7	62.7	80.4	0.0	0.0	0.3	211.9
	618	26	9.0	9.0	29.4	9.6	39.0	0.0	0.0	0.1	99.9
SV	753	14	14.1	7.9	5.8	17.1	23.9	0.1	0.0	0.0	74.8
	785	12	12.2	7.4	19.4	31.6	51.0	0.0	0.0	0.5	134.1
4 OCTOBER											
NEGV	614	24	27.4	15.1	21.1	99.9	121.0	0.2	0.0	0.1	289.0
	618	26	13.1	7.2	32.6	4.9	37.5	0.0	0.0	0.2	98.1
SV	753	14	6.7	0.8	25.6	9.5	35.1	0.0	0.0	0.0	79.5
	785	12	5.7	5.1	57.7	5.8	63.5	0.0	0.0	0.1	140.7
27 NOVEMBER											
NEGV	614	24	40.9	10.8	91.4	13.0	104.4	0.8	0.5	0.5	280.4
	618	26	16.5	4.0	17.8	11.3	29.1	0.8	0.6	0.1	90.3
SV	753	14	12.1	1.5	16.1	16.8	32.9	0.6	1.3	0.5	89.3
	785	12	37.5	4.2	18.5	8.1	26.6	0.4	0.0	1.0	111.3
BP	394	29	42.5	5.7	9.7	27.4	37.1	0.9	1.4	0.8	168.7
	397	9	26.1	3.0	9.6	13.7	23.3	1.5	1.5	0.4	94.1

a higher total density than the "injured" #397, the results were not consistent. For example, although the NEGV trees #614 and 618 had very similar oxidant injury ratings, there was a considerable difference in total microarthropod density. This differential may be due primarily to disturbance of the forest floor by human activity. The two trees at SV also had different abundance levels. In this case, the higher density of microarthropods under #785 may in part be due to the fact that the tree is not particularly isolated and litter fall from nearby healthier trees could have influenced the forest floor under the sample tree. Without these disturbances, differences between oxidant air pollutant "injured" and "healthy" trees might have been greater, as with the trees at Breezy Point, and emphasize the importance of critically evaluating between-tree variation.

Effects on Microbial Activity in Needle Litter Decomposition and Nutrient Cycling

In the forest, there is a constant turnover of tree biomass as old foliage, branches and trees die and fall and others grow to replace them. Litter decomposition and nutrient cycling are the means by which the living forest recovers much of the nutrient tied up (incorporated) in this organic matter. The recovery of these vital nutrients is the function of the vast populations of litter and soil microflora and microfauna. This portion of the overall study is directed toward determining the influence of oxidant air pollution on microfloral populations and leaf litter decomposition (primarily ponderosa and Jeffrey pines) as indicated in Figure 60. Previous work in this field is

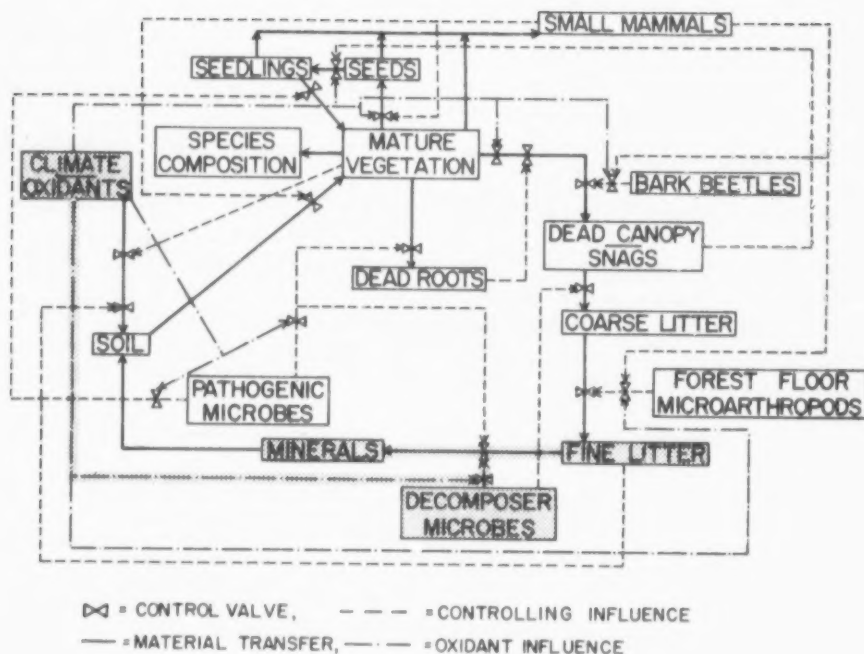


Figure 60. Needle litter decomposition subsystem.

relatively sparse. Recent reviews are available (Dickinson and Pugh, 1974).

Needle Litter Decomposition in Natural Stands ---

Quantification of integrated needle litter decomposition in the field is in progress. Data from this type of experiment will help determine how oxidant air pollution affects the quality of needles as substrates for decomposers and as sources of nutrients for cycling, and how it affects the capacity of naturally-occurring populations of litter microorganisms to decompose pine needle litter.

For such a study, co-dominant or dominant, relatively isolated

trees have been selected. Two of the least, and two of the most, oxidant injured Jeffrey pine trees were selected. The selected sites included Holcomb Valley, "no" oxidant injury, and at Camp Osceola, "moderate" oxidant injury. Similar selections of ponderosa pines were made at Barton Flats, "moderate" oxidant injury, and at Camp O-ongo, "moderate - heavy" oxidant injury. These sites represent the range of oxidant injury represented in each species on the study plots.

Freshly fallen litter was collected from each selected tree and subsamples were randomly made. One subsample was taken for subsequent nutrient analysis. In fall, 1974, twenty subsamples were placed in nylon mesh envelopes. One subsample each was taken for microarthropod census prior to and approximately five weeks after placement in the field. Figure 61 relates the sources and disbursement of the mesh decomposition envelopes.

After one year in the field, one-half of the replicates of each treatment will be retrieved and a) the microarthropod population will be recensused, b) change in dry weight for each replicate will be determined, and c) the change in nutrient status of the needles will be determined. The remaining envelopes will be retrieved after two years in the field and will be handled in the same manner as the first year envelopes.

This type of experiment ties in broadly with other aspects of the overall project. The soil moisture and temperature data being collected by the soils group, as well as precipitation and air temperature estimates for the involved sites will be used in the interpretation of data collected. The cooperative efforts of the microflora and micro-

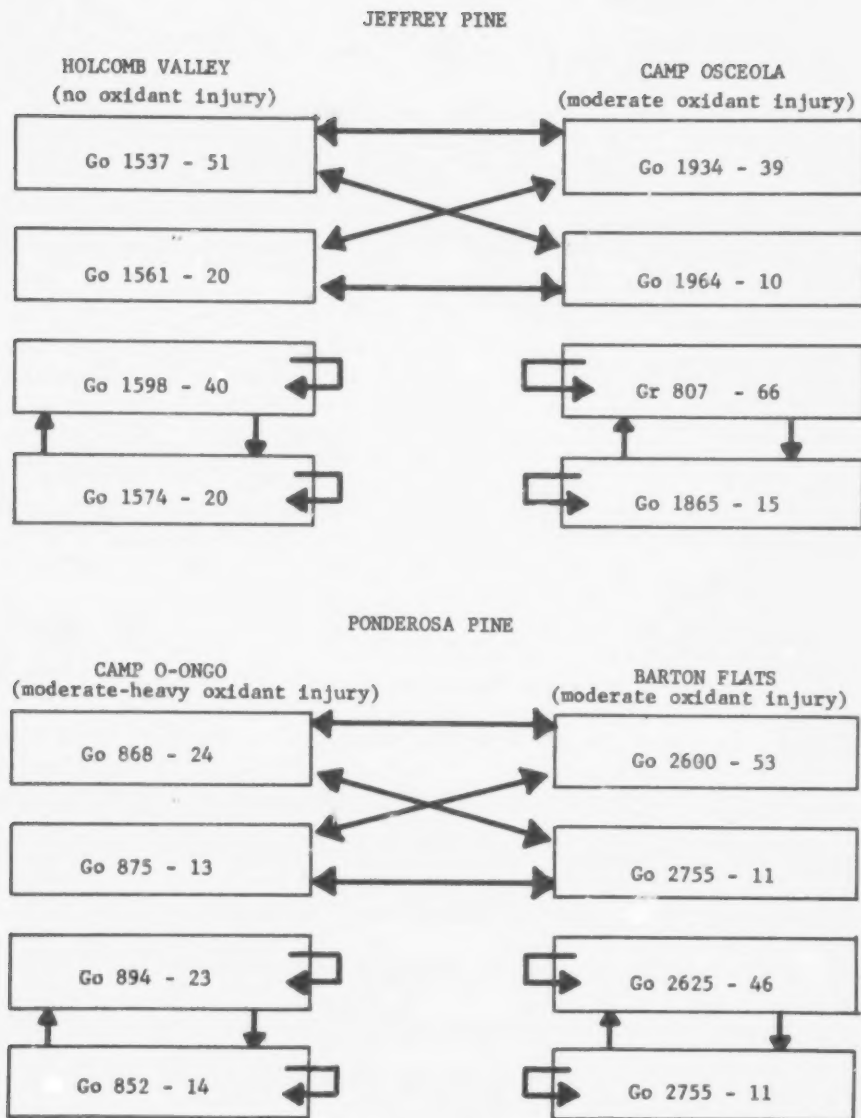


Figure 61. Source and location of decomposition study envelopes. Left portions of codes represent tree tag number; right portion indicates 1973 oxidant injury score of tree. Arrows represent 10 litter envelopes and point from sources to present locations.

fauna are under study here. In the sense that many pathogenic fungi have active saprophytic roles, their decompositionalefforts are included in the total observed rates.

Analysis of the materials now in the field will be completed in approximately two years. Further similar experiments involving the same, and perhaps additional, trees will be necessary in order to substantiate the results of this first run. Some of these are planned to begin in the fall of 1975.

Laboratory Decomposition of Conifer Needle Litter With Various Degrees of Oxidant Injury ---

A pilot experiment on pine needle decomposition in the laboratory was begun in December, 1973. This experiment tested a method and also provided information on relative differences in needle decomposition rates between four sites, two trees of different oxidant injury scores on each of those sites, and incubation at two different temperatures. Relatively isolated co-dominant to dominant trees were selected on each of four plots: Breezy Point (ponderosa pine, "moderate" oxidant injury), Dogwood (ponderosa pine, "moderate" oxidant injury), Snow Valley (Jeffrey pine, "moderate" oxidant injury), and U.C. Conference Center (ponderosa pine, "moderate" oxidant injury). Twenty equal lengths of needle from one of the trees were weighed (air-dried to a constant weight at approximately 22 C and 42 percent relative humidity) for each replicate. One-half of the replicates were sterilized with propylene oxide. Each replicate was then placed on one gram of hand-crumbled duff from its source tree on clean paper towelling inserted into a large test tube (o.d. 2.5 cm). One-half of the replicates were incu-

bated at room temperature; the other half at 12 C. Distilled water was added four times during the winter and withheld for the remainder of the experiment. Fourteen months after initiation of the experiment, the needles were separated from the duff, air-dried and weighed. Air-dry weight losses were calculated as percent of original weight and analyzed by one-way analysis of variance.

Average percent weight loss was significantly greatest (95 times in 100) for needles from Breezy Point (33%), insignificantly different between U.C. Conference Center (26%) and Snow Valley (25%), and significantly least for Dogwood (20%). At Breezy Point, needles from the healthier of the two trees (oxidant injury scores 17 and 6) lost significantly more weight. The two trees involved at U.C. Conference Center (oxidant injury scores 11 and 7) and Snow Valley (oxidant injury scores 27 and 13) did not differ significantly. At Dogwood, needles from the less healthy tree (oxidant injury scores 25 and 6) lost significantly more weight. Analysis of the effect of incubation temperature on percent weight loss suggests that temperature can be a factor in needle decomposition rate. Where there was a significant difference between incubation at 12 C and room temperature (the unhealthy tree at Breezy Point and the healthy tree at Snow Valley), greater decomposition occurred at room temperature.

This type of needle decomposition test in the laboratory shows promise for future use. Plans are developing for experiments on the effects of fumigation on decomposition. Sterilized needles from trees involved in the integrated field needle decomposition study will be inoculated with individual isolates of predominant organisms and sub-

jected to fumigated or filtered air as well as incubation at room temperature or 12 C.

Oxidants and Decomposer Microorganism Populations on Needle Litter in Natural Stands ---

Oxidant air pollution may alter the rate of pine needle decomposition by affecting the composition of microbial populations on senescing and fallen needles. To study the succession of litter microorganisms, three lines of investigation are being followed in the field.

One square meter of nylon mesh material has been placed (September and early October, 1974) approximately two-thirds of the crown radius out from the stem beneath each of 29 trees on seven major plots, including all trees involved in the integrated field needle decomposition study and most of the trees in the cooperative microorganism survey.

In addition, four trees have been tagged at each of two locations on the University of California Blodgett Experimental Forest, El Dorado County, California. They are tagged Gr 1-8, and each has a nylon mesh square under it. Blodgett was selected as a mixed conifer area with very little air pollution damage. It is felt that ponderosa stands outside the SBNF must be considered for comparison in terms of air pollution impact. Periodic samples of litter from these nets will be incubated and analyzed for diversity and populations of microorganisms present. Additional mesh squares will be set out annually beneath each tree, separating annual litter increments. In this way, the annual and seasonal succession of microflora will be elucidated.

In order to determine the degree of colonization of needles while still on the trees, the lowest healthy twig on the north, east, south,

and west sides of the stem was clipped from the trees involved in the field gross needle decomposition study and from each of the eight trees tagged at Blodgett. The annual needle complements were separated in the field, and their fungal populations are being characterized and estimated in the lab. Data for one tree (Barton Flats Go 2600, P. ponderosa, oxidant injury score 53) has been compiled. Twenty-four categories of fungi were isolated. Alternaria sp., Cladosporium sp., Aureobasidium sp., Penicillium spp., and an unidentified fungus designated "tan fruiting body" occurred at all aspects. Of these five, Cladosporium sp. and Penicillium spp. were probably surface contaminants in most cases as surface sterilization (one minute drench in 10% chlorox drastically reduced their numbers. Aureobasidium sp. and, to a lesser extent, Alternaria sp. may have considerable internal as well as external populations, as surface sterilization had much less effect on their numbers. "Tan fruiting body" was virtually unaffected by surface sterilization and may well exist internally. Of the four directions studied, southern exposure appeared to be harshest. Only Alternaria sp. and Aureobasidium sp. were abundant on this aspect.

Samples of the organic matter horizons are being collected in conjunction with, and immediately adjacent to, samples for microarthropods. Direct plating of litter and fermentation zones, coupled with dilution plating of humus, will relate the occurrence of fungal and microarthropod populations to each other. Available data on precipitation, air and soil temperature and soil moisture will be incorporated into the analysis. This cooperative litter microorganism survey will increase in value as the data base expands.

The nature of the studies outlined above dictates that a number of years of data are requisite for the substantiation of results obtained.

Response of Selected Fungal Species and Fungus/Mite Associations to Ozone Fumigations in the Laboratory ---

This phase of the project is designed to determine how air pollution a) affects growth and reproduction of microbial species involved in litter decomposition, b) affects rates of needle decomposition by major microorganisms and c) affects selected litter mites cultured with litter fungi.

Species of fungi isolated from litter samples will be fumigated at a number of concentrations of ozone. The effects of ozone will be quantified on such factors as a) colony growth rate, b) rate of spore production and c) percent spore germinability. Two clear plexiglass fumigation chambers were designed and constructed for this use inside the two walk-in growth chambers on the Oxford Field Tract, University of California, Berkeley. These two walk-in chambers are nearly renovated to permit control of light, temperature, relative humidity and ozone concentration. Twelve similar opaque plexiglass fumigation chambers have been designed for fumigation of woody litter decay tests and Fomes annosus soil block decay tests.

A technique similar to the laboratory gross needle decomposition method reported above will be employed for the fumigation of various needle/fungus combinations.

As techniques for culturing mites with important litter fungi become worked out, cooperative in vitro tests of the effects of ozone on these associations will be possible.

CONSEQUENCES FOR RENEWAL OF BIOLOGICAL RESOURCES FOR HUMAN WELFARE

Cone and Seed Production for Dominant Conifer Tree Reproduction

To persist, a forest must reproduce itself. This involves the process of seed production, seed germination, and seedling establishment. In coniferous forest species, seed production is accomplished by the production of an annual cone crop whose abundance varies widely each year (Pearson, 1923; Roeser, 1941; Boe, 1954; Fowells and Schubert, 1956; Daubenmire, 1960; Larson and Schubert, 1970). The causes of these annual fluctuations are unknown, but they are thought to be partially the result of weather patterns (Maguire, 1956; Daubenmire, 1960; Lowry, 1966; Puritch, 1972). Furthermore, each species differs in the amount and frequency of the cone crops it produces (Fowells and Schubert, 1956). This difference, coupled with differing requirements for seed germination, seedling establishment and seedling survivorship by each species, determines the rate of change in the species comprising a stand. Measuring the cone crop patterns of each species thus become important in understanding stand succession.

The mixed conifer forests of the SBNF have had a history of photochemical oxidant air pollution exposure, principally ozone (Miller and Millecan, 1971). Of the species comprising this forest type, ponderosa, Pinus ponderosa, Lawson, and Jeffrey pine, P. Jeffreyi, Greville and Balfour are the two species most sensitive (Miller and Millecan, 1971). In these pines, exposure to ozone reduces the rate of photosynthesis and injures the needle tissue. Both of these effects lead to premature needle abscission (Miller et al., 1969; Evans and Miller, 1972;

Miller, unpublished data). Ponderosa and Jeffrey pines injured by ozone have crowns which appear similar to those used to define the low vigor classes employed in rating pines subjected to higher risks of bark beetle attack (Keen, 1936) and in evaluating the growth potential of pines following selective logging (Hornibrook, 1939; Thomson, 1940). Larson and Schubert (1970) using the vigor classes employed to evaluate growth potential (Thomson, 1940), found that trees of low vigor (sparse complement of needles within the crown) produced substantially fewer cones. Therefore, the sparse crown foliage resulting from abscission of ozone injured needles, coupled with reduced photosynthesis in those needles that remain, suggests that oxidant sensitive trees may produce fewer and smaller cones, less frequent cone crops,

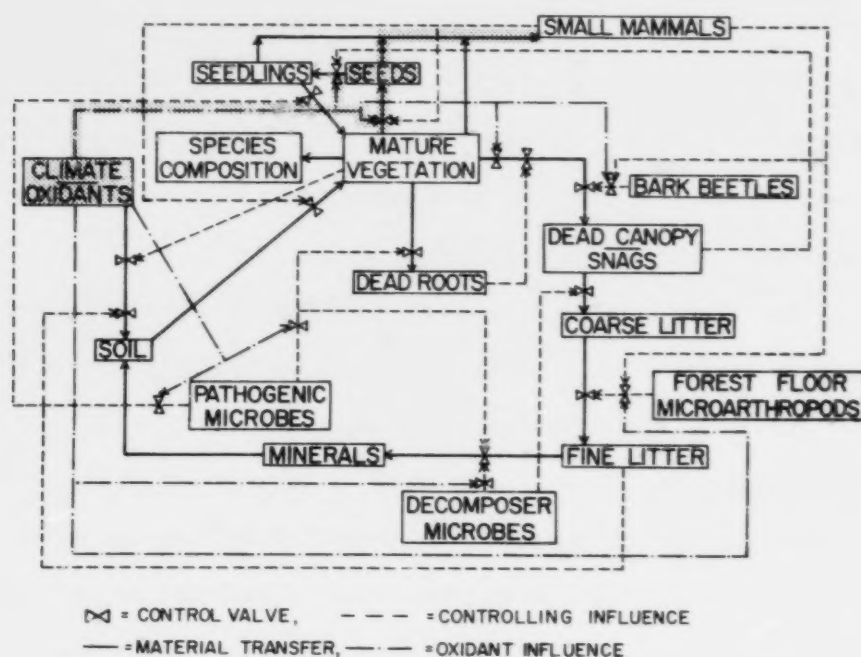


Figure 62. Conifer seed production subsystem.

fewer seeds per cone, and lower seed viability. This subsystem is indicated in Figure 62.

Objectives ---

One objective of this study is to test the hypothesis that cone crop abundance and frequency in ponderosa and Jeffrey pine are affected by ozone injury. A second objective is a description of the probability of a given tree producing a cone crop in a given year. A number of factors are known to affect cone production (Fowells and Schubert, 1956; Larson and Schubert, 1970); hence, this description will require the identification of certain tree characteristics, such as species, age class, vigor class, ozone injury class, and other variable such as temperature patterns or soil moisture depletion rates which are likely to affect that probability. The description will be used in a submodel of cone production and can be integrated with a stand succession model.

Estimating Cone Crops ---

The cones within the crowns of all conifers on the 18 established plots were visually counted with the aid of binoculars. Although these counts underestimate the actual number of cones within the crown, they reveal the pattern of annual cone production, identify those trees which produce cones, and provide an order of magnitude estimate of cone abundance (Roeser, 1941; Fowells and Schubert, 1956, Daubenmire, 1960). Their inaccuracy, however, suggests the need for a second estimate of cone abundance. This second estimate will be obtained by counting the cones after they have fallen to the ground. They will be recorded by assigning them to the trees from which they fell. In cases where the

crowns of two or more trees are interlaced, the cones will be partitioned among the trees in proportion to the number of cones counted in each of their crowns. (This latter point suggests a fourth reason for the need of visual cone counts.) The cones will be collected periodically in the spring and summer of the year following a given cone crop. Very few cones from the previous year's crop remain in the tree crowns by the time the next crop is produced (Larson and Schubert, 1970). Counts of cones on the ground are applicable only to the pines (sugar pine, ponderosa pine, Jeffrey pine), and possibly to incense cedar, Libocedrus decurrens Torrey. Cones can be counted on the ground and their year of production determined (Pearson, 1923; Larson and Schubert, 1970). The cones of white fir, Abies concolor, disintegrate in the process of seed dispersal.

Cones collected in the 18 plots are used to estimate the incidence of cone insects, the incidence of predation on cones by squirrels, and the frequency distribution of seeds produced per cone. The incidence of cone insects is obtained by placing a number of cones, individually, in containers and rearing out the insects they contain. The specimens which emerge are identified and their damage characteristics determined. An estimate of the number of seeds per cone is made by counting the number of seed niches present in the bracts in fifty cones. These cones are also cut along the axis and the presence or absence of insect damage noted. Incidence of cone predation by squirrels is evidenced as the number of immature cones on the ground upon which feeding has occurred. The effect of squirrel predation is being studied in conjunction with investigations on small mammals.

Additional information is being taken from trees on all of the plots. Trees are classified on the basis of their age, height, crown class (Table 18), vigor class (Figure 63), length of live crown and location within a stand (on the margin or in the interior).

TABLE 18. DESCRIPTION OF CROWN CLASS CHARACTERISTICS

<u>Crown Class</u>	<u>Description</u>
Dominant	Trees whose crowns extend above the general crown level.
Codominant	Trees whose crowns form the general crown level.
Intermediate	Trees whose crowns extend into the general crown level.
Intermediate Open	Trees substantially smaller in diameter and height than those that generally characterize the stand but are isolated, free to grow on all sides.
Intermediate Suppressed	Trees which are of similar diameter as those which generally characterize the stand but whose crown lies entirely below the general crown level.
Suppressed	Trees which are smaller in diameter than those which generally characterize the stand and whose crown lies entirely below the general crown level.

All these factors are known to be associated with cone abundance and cone crop frequency (Fowells and Schubert, 1956; Larson and Schubert, 1970). These additional data have been taken on 8 of the 18 plots. Additional plot and tree data will be obtained from the other subprojects and this subproject will supply data to them in return. Multi-

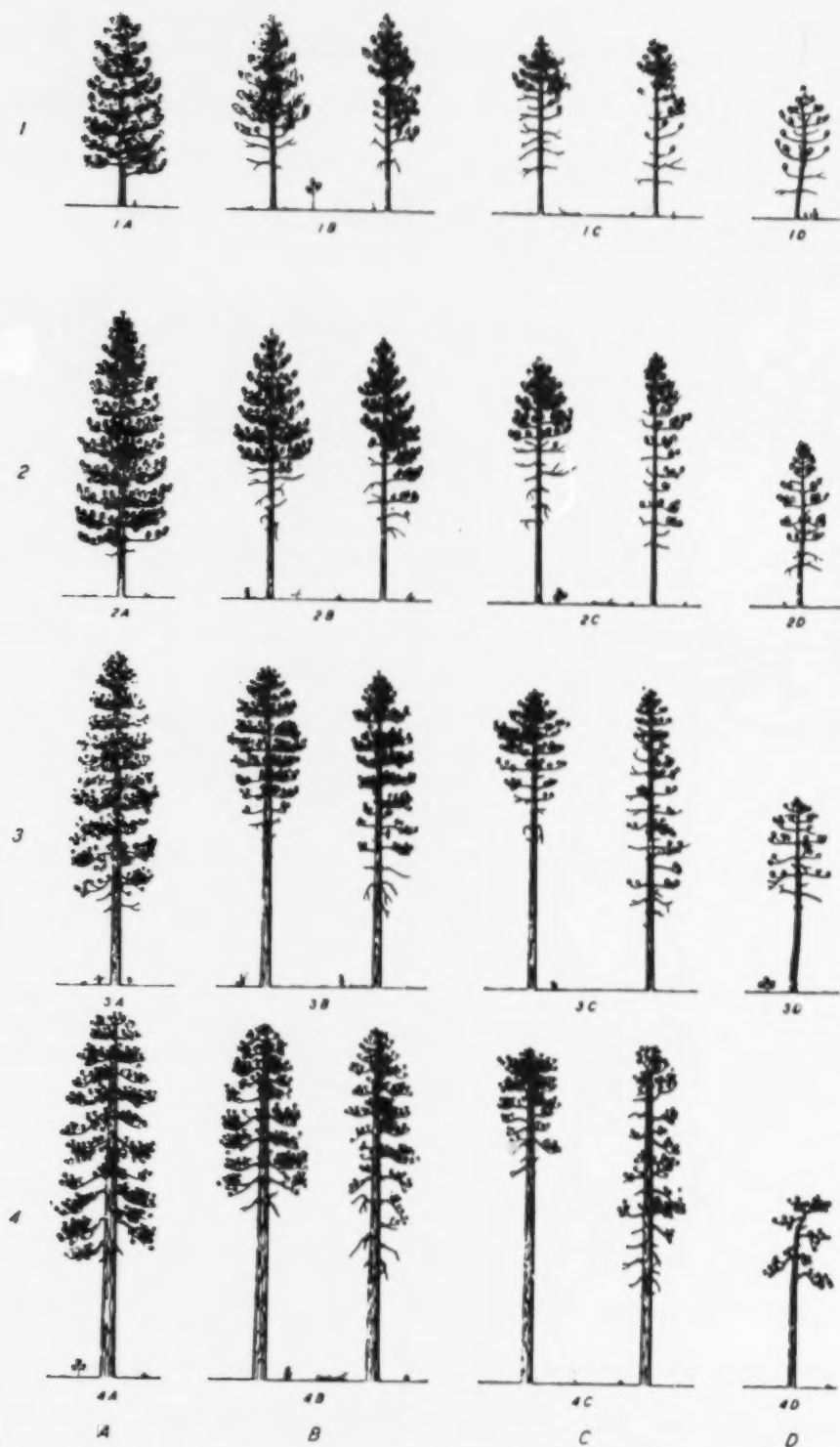


Figure 63. Examples of Keen's tree age and growth vigor classes for east side Sierra Nevada and southern California ponderosa pine (Keen, 1936).

variate analysis (multiple regression, stepwise regression or variance-covariance analysis, for example) will be used to identify the relationship of cone crop to the independent variables discussed above.

Counts of Cone-Bearing Trees and Cone Production ---

Most of the data presented below is preliminary. The 1974 cone crop was the first crop visually counted in the 18 plots. Only a portion of the plots were counted in 1973 because plot establishment was not completed prior to the loss of many of the cones from the trees. Lack of these counts prevented assigning the fallen cones to the trees from which they came, in those tree groups whose crowns interlaced. Furthermore, cone data for 1973 do not include losses due to insects or squirrels. The 1973 cone data, however, provide a reliable estimate of the number of trees which produced a cone crop. Ground counts of the cone crop will begin in spring 1975 and will represent the count of the 1974 cone crop. Cones lost to insects, squirrels, and unknown sources will be incorporated into these counts. It should be noted that most all of the additional tree and plot data are still being acquired; thus the effect of oxidants on cone production in ponderosa and Jeffrey pine cannot be addressed, as the data are still in various stages of analysis.

Table 19 summarizes the visual cone counts for both the 1973 and 1974 cone crops. The characteristics of the crown classes are listed in Table 18. The visual counts for Jeffrey and ponderosa pine are summarized by plot in Appendix O.

A greater percentage of trees in the dominant crown class produced

TABLE 19. INFLUENCE OF CROWN CLASS ON THE NUMBER OF TREES WHICH PRODUCED CONES AND THE NUMBER OF CONES PRODUCED BY PONDEROSA AND JEFFREY PINE IN 1973 AND 1974 IN 18 PLOTS.

Year	Numbers	Crown Class				
		Dominant	Codominant	Intermediate	Intermediate Open	Intermediate Suppressed
1973	# trees	357	277	122	151	68
	# trees with cones	144	45	3	6	0
	total cones	4,230	900	9	15	0
	% trees with cones	40.34	16.24	2.46	3.97	0
1974	average # cones/cone tree	29.38	17.77	3.0	2.5	0
	# trees	482	425	329	235	73
	# trees with cones	285	139	20	6	2
	total cones	18,645	4,183	320	108	2
	% trees with cones	59.13	32.70	6.08	2.55	2.74
	average # cones/cone tree	65.41	30.09	16.0	18	1.0
						0

cones. Codominant trees were the second most frequent bearers (Table 19). In those trees that bore cones in 1973 or 1974, dominant trees produced a little more than double those produced by codominant trees. In 1973, of the 198 trees, 73 percent were dominant, 23 percent were codominant, 1.5 percent were intermediate, while the remainder, 3 percent, were intermediate open. A similar pattern was evident in the 1974 cone crop. Of the 452 trees which bore cones in 1974, 63 percent were dominant; 31 percent were codominant; 4.4 percent were intermediate; 1.3 percent were intermediate open, 0.01 percent were intermediate suppressed. Clearly, the dominants are the greatest contributors to the cone crop. These findings agree with those of Pearson (1923), Fowells and Schubert (1956), and Larson and Schubert (1970). One other point should be emphasized regarding the class of trees which are the greatest contributor to the cone crop; the larger the tree, the greater the number of cones produced, and the relationship appears to be non-linear (Pearson, 1923; Larson and Schubert, 1970). Appendix O provides a further breakdown of cone production by plot and species.

Tentatively, the type of trees contributing the most cones to a given annual crop are those which have a large diameter (larger than 50 cm), are isolated from their neighbors or on a margin of a stand, have a good complement of needles, and belong to the dominant crown class.

Seed Production ---

Cones were collected from seven plots to estimate the number of seeds produced per cone in 1973. The plots and the resultant data are

shown in Table 20.

TABLE 20. CONIFER SEED PRODUCTION FROM SELECTED STUDY SITES

Plot	Seeds/Cone		No. of Cones in Sample	Pine Species
	(Mean	Standard Deviation)		
Tun 2	45.70	± 12.31	50	PP
GVC	28.26	± 13.17	50	JP
CAO	41.16	± 13.41	50	JP
BF	53.18	± 22.57	50	JP,PP
SF	66.92	± 26.56	50	PP
CA	52.90	± 23.95	50	PP
BP	42.50	± 40.95	12	PP

Ignoring Breezy Point because of the small sample size, 12 cones, the remaining six plots can be divided into two groups based on the standard deviations of the number of seeds per cone. The reasons for these two groups are unclear. It is not based on tree species, since the trees at Tunnel Two are predominantly ponderosa pine and those at Green Valley Creek and Camp Osceola are Jeffrey pine. Moreover, the trees at Sky Forest and Camp Angelus are ponderosa pine, while those at Barton Flats are a mixture of Jeffrey and ponderosa. More data collected from a larger number of plots and from a number of years will be needed before the consistency of these relationships can be accepted.

Agents of seed mortality: insects --- Insect damage to cones produced in 1973 was assessed in six plots. The results were variable: Tun 2 had 2 percent of its cones infested, SF had 22 percent, CA had 6 percent,

and the remaining three plots showed no sign of cone insect activity. All of the infested cones in this year were from ponderosa pine. The majority of insect damage was caused by the cone moth Lasperyia sp. (Lepidoptera: Olethreutidae), but the moth damage was less than 15 percent of the seeds in the infested cones. The larvae of this moth bore into the seed while the cone is immature, consuming the seed content in the process of developing. The moth larvae leave the seeds by boring into the cone axis, where they pupate and emerge. They leave the hollowed out seeds firmly attached to the cone axis, along with larval mines and cast skins (shed following the moths' pupation) as evidence of their presence.

A second insect Ernobius fissuratus Fall (Coleoptera: Anobiidae) has been found infesting cones in the SF plot. Fourteen percent of the cones collected from the SF plot showed evidence of damage. Cone bracts riddled with holes were the damage characteristics of this insect.

Agents of seed mortality: squirrels --- Squirrels accounted for the greatest single loss of cones. This loss, however, occurs only in the last summer of cone maturation. Ponderosa and Jeffrey pine take two years to develop and mature (Roeser, 1941; Mirov, 1967). The impact of squirrel predation on the cone crop has not yet been analyzed. For further discussion of squirrel predation see the following section on wildlife. The amount of data collected to date, and the stage of their analyses, prevents discussion of the two main objectives outlined in the introduction. Cone crop frequency can only be obtained after a number of cone crops have been followed (Fowells and Schubert, 1956;

Larson and Schubert, 1970). The 1974 cone crop was larger than usual according to personnel familiar with the area. It is too early to judge what a large cone crop means in terms of established seedlings, or how frequently such a crop occurs.

Distribution and Role of Wildlife Populations Under Oxidant Stress

Wildlife species form an important component of all forest ecosystems. As consumers, for example, wildlife often have a major influence on forest plant succession patterns (Lawrence, 1958; Hooven, 1969). Changes in wildlife abundance, or species mix, induced by the direct or indirect effects of oxidant air pollution potentially could affect forest plant succession.

Objectives and Study Procedures ---

The goal has been to describe the terrestrial vertebrate community within this mixed conifer forest, particularly in relation to ponderosa and Jeffrey pine; and to determine the effects of oxidant air pollutants upon this vertebrate community

Field work was conducted during the summers of 1972, 1973, and 1974. Initially, we prepared preliminary lists of vertebrates found in the study area (White and Kolb, 1973). Small mammals were chosen for detailed study because of their important interactions within this forest system, Figure 64, because they are numerous and widespread through the forest, and because this group of vertebrates can be studied easily with simple procedures. Standard Calhoun Type B snaptrap lines were used (Calhoun, 1959). Lines were established on each of the six plots

trapped in 1972 (Kolb and White, 1974), and on an additional eleven plots in 1973 (White, 1974). This widespread trapping provided a

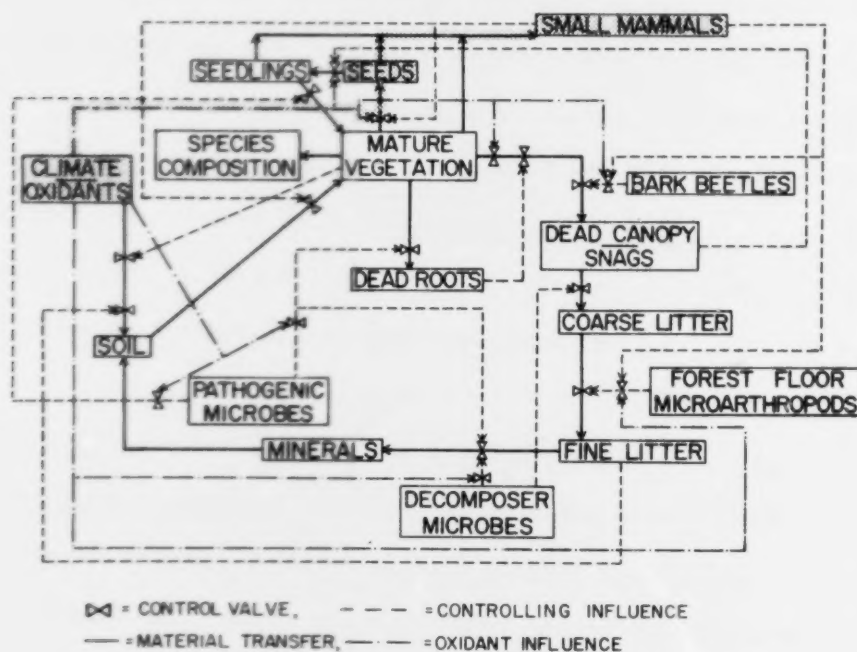


Figure 64. Wildlife subsystem.

sample of small mammal distribution and abundance throughout the forest, in addition to data on sex and age ratios, reproductive performance, health, physical condition, and food habits of these populations. The ecology of the western gray squirrel (*Sciurus griseus*), and its impact upon conifer seed crops, also has received detailed study because of its abundance and the important role it plays in the functioning of this forest.

Small Mammal Distribution and Oxidant Concentrations ---

We captured 405 small mammals on the permanent study plots in 1972-1974, Table 21. There was considerable variation in the number of small mammals captured year to year and from one plot to another (Figure 65). Overall, the greatest number was captured in 1974 and the fewest animals were captured in 1973. Much of the fluctuation can be accounted for by fluctuations in the numbers of deer mice (Peromyscus spp.) and harvest mice (Reithrodontomys megalotis). For example, the number of deer mice captured on the six original plots was 45 in 1972, 15 in 1973, and 118 in 1974. Harvest mice increased in incidence of capture from 0 in 1972 and 1 in 1973, to 9 in 1974.

The paucity of larger species, dusky-footed woodrat (Neotoma fuscipes) and golden-mantled ground squirrel (Callospermophilus lateralis), in 1972 was largely a result of using only small museum special (mouse) traps during this first trap-year. The marked increase of both species in 1973 and 1974 is coincident with the use of rat traps in addition to the museum special traps.

Deer mouse populations characteristically fluctuate dramatically (Hooven, 1969). We are currently comparing the amplitude and pattern of these fluctuations in the San Bernardino National Forest with fluctuations reported in other forests.

The data suggest a relationship between oxidant air pollutant concentrations and the number of small mammals captured (Figure 66). During trap-years 1972-1974, 238 animals were trapped on plots with "no" or "light" pollution, 120 on "moderate" plots, and 48 on plots with "heavy" oxidant air pollution. In 1974, we did additional trapping

TABLE 21. SMALL MAMMAL SPECIES CAPTURED PER PLOT, 1972-1974
(Number)

PLOT	SPECIES									TOTAL
	P.sp.	E.sp.	C.l.	N.f.	M.c.	R.m.	S.b.	G.s.	D.a.	
SC	72	17	3	18	0	0	1	0	0	111
HB	28	26	11	4	3	0	0	0	2	74
SV	40	9	8	5	5	0	1	0	0	68
CA	19	0	1	0	0	0	0	1	0	21
BF	16	0	0	0	2	0	1	0	0	19
DW	3	4	0	0	0	10	0	0	0	17
BL	13	9	4	0	0	0	0	1	0	27
NEGV	5	3	0	0	3	0	0	0	0	11
TUN2	9	1	0	0	0	0	0	0	0	10
GVC	8	0	0	0	0	0	1	0	0	9
UCC	0	9	0	0	0	0	0	0	0	9
SCR	8	0	0	0	0	0	0	0	0	8
BP	6	0	0	0	0	1	0	0	0	7
COO	1	3	0	0	1	0	0	0	0	5
HV	4	0	1	0	0	0	0	0	0	5
NWCP	1	0	0	0	0	1	0	1	0	3
SF	<u>1</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>1</u>
TOTAL	234	81	28	27	14	12	4	3	2	405

P.sp. - Peromyscus sp.

E.sp. - Eutamias sp.

C.l. - Callospermophilus lateralis

N.f. - Neotoma fuscipes

M.c. - Microtus californicus

R.m. - Reithrodontomys megalotis

S.b. - Spermophilus beecheyi

G.s. - Glaudomys sabrinus

D.a. - Dipodomys agilis

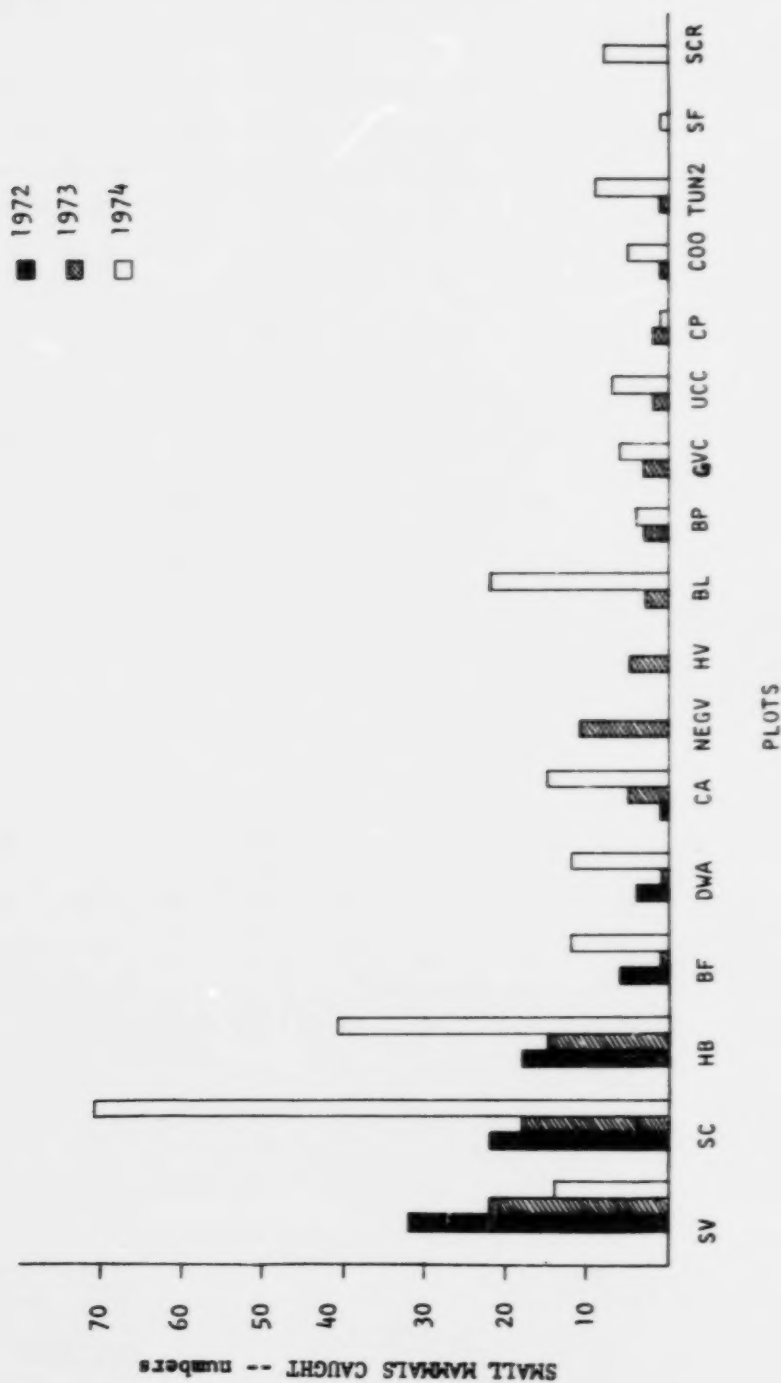


Figure 65. Number of small mammals caught per year per plot

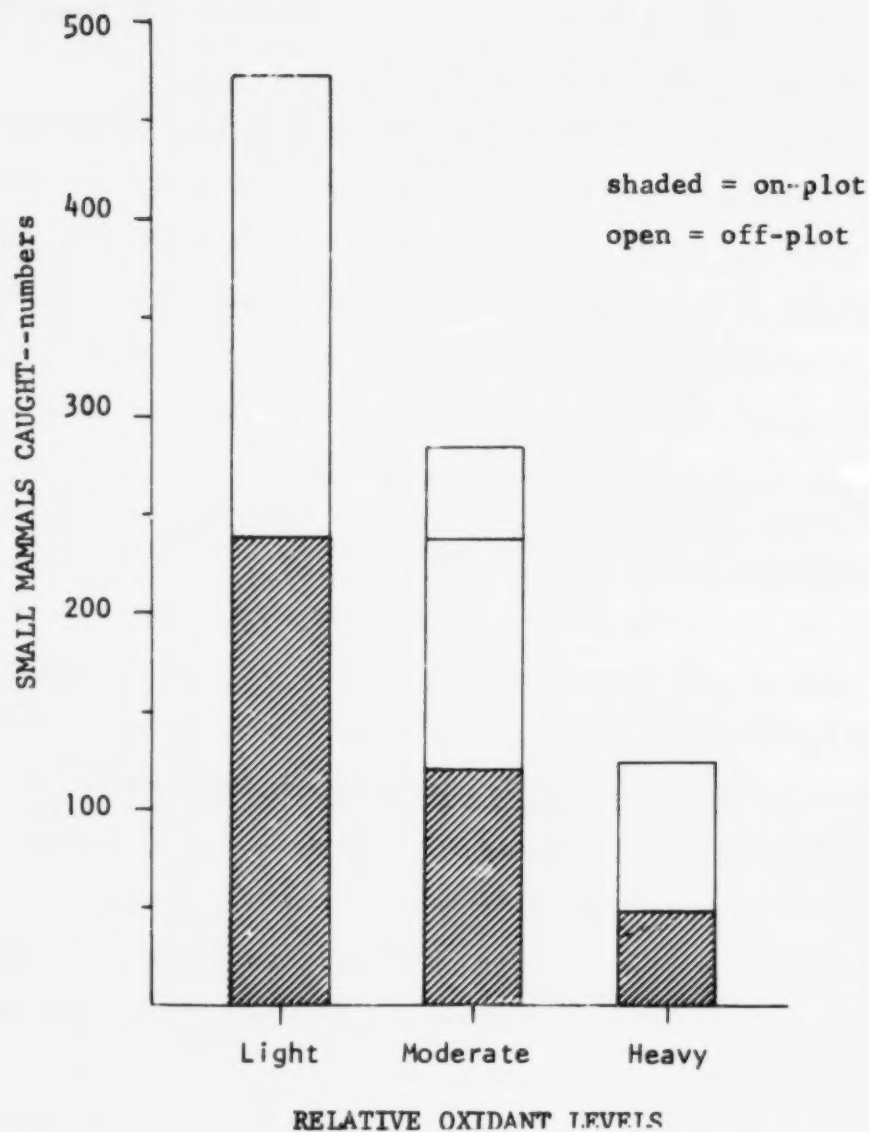


Figure 50. Number of small mammals caught on plots with light, moderate, and heavy oxidant air pollutant levels. A value equal to the average catch per moderate plot was added to the moderate level column because only five moderate plots were sampled compared to six for both light and heavy plots. On-plot, 1972-74; off-plot, 1974.

in adjacent off-plot locations; 233 animals were trapped on plots with "no" to "light" pollution, 116 on "moderate" plots, and 74 on "heavy" plots (Figure 66).

This relationship also appears to exist between the oxidant air pollutant injury rating for the plots (White and Kolb, 1973; White, 1974) and the number of animals captured. It is likely that the abundance of small mammals is affected more importantly by other aspects of habitat quality (e.g., food and cover abundance) than directly by levels of oxidant air pollution. However, we are continuing to investigate these relationships.

Conifer Seed Predation by Squirrels ---

Detailed study of the ecology of the western gray squirrel began in 1973 and will continue through 1975-76. Abundant throughout the conifer forest the gray squirrel depends on the yellow pine - black oak (Pinus ponderosa - Quercus kelloggii) vegetation mosaic for food, cover, and nest sites (Figure 67). The seed-squirrel relationship is very important in this forest system. Other factors of importance in controlling seed availability for conifer tree reproduction have been discussed in a preceding section of this report. An alteration of the balance between pine and oak through the agency of oxidant air pollution, or a change in the squirrel population directly due to oxidants, will affect the balance of the seed-squirrel relationship and have a significant influence on the forest, especially pine and oak reproduction. We are comparing what is found in the SBNF with what is reported elsewhere in forests not affected by oxidants.

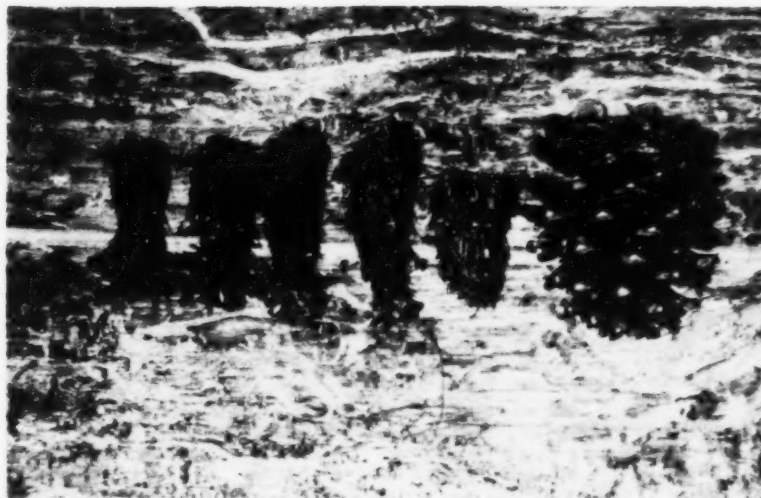


Figure 67. Immature cones stripped of seed by the gray squirrel (left) compared to a single mature cone of ponderosa pine (right).

We live-trapped and ear-tagged 43 squirrels (23 male : 20 female) on six study plots. Preliminary census results indicates a large, widespread population of gray squirrels, with small areas of unusual density. For example, on the Sky Forest plot, 18 individuals were tagged in six trap-days on an area of less than 0.2 hectares.

According to our measurements, yellow pine cone production increased in 1974 over 1973. The number of cones destroyed for seed eating by gray squirrels also was higher in 1974 than in 1973 (Figure 68). Squirrels generally utilized the same trees in both years. Only four trees that were heavily utilized in 1973 were not used in 1974. All other trees heavily used in 1973 produced cones and were utilized in

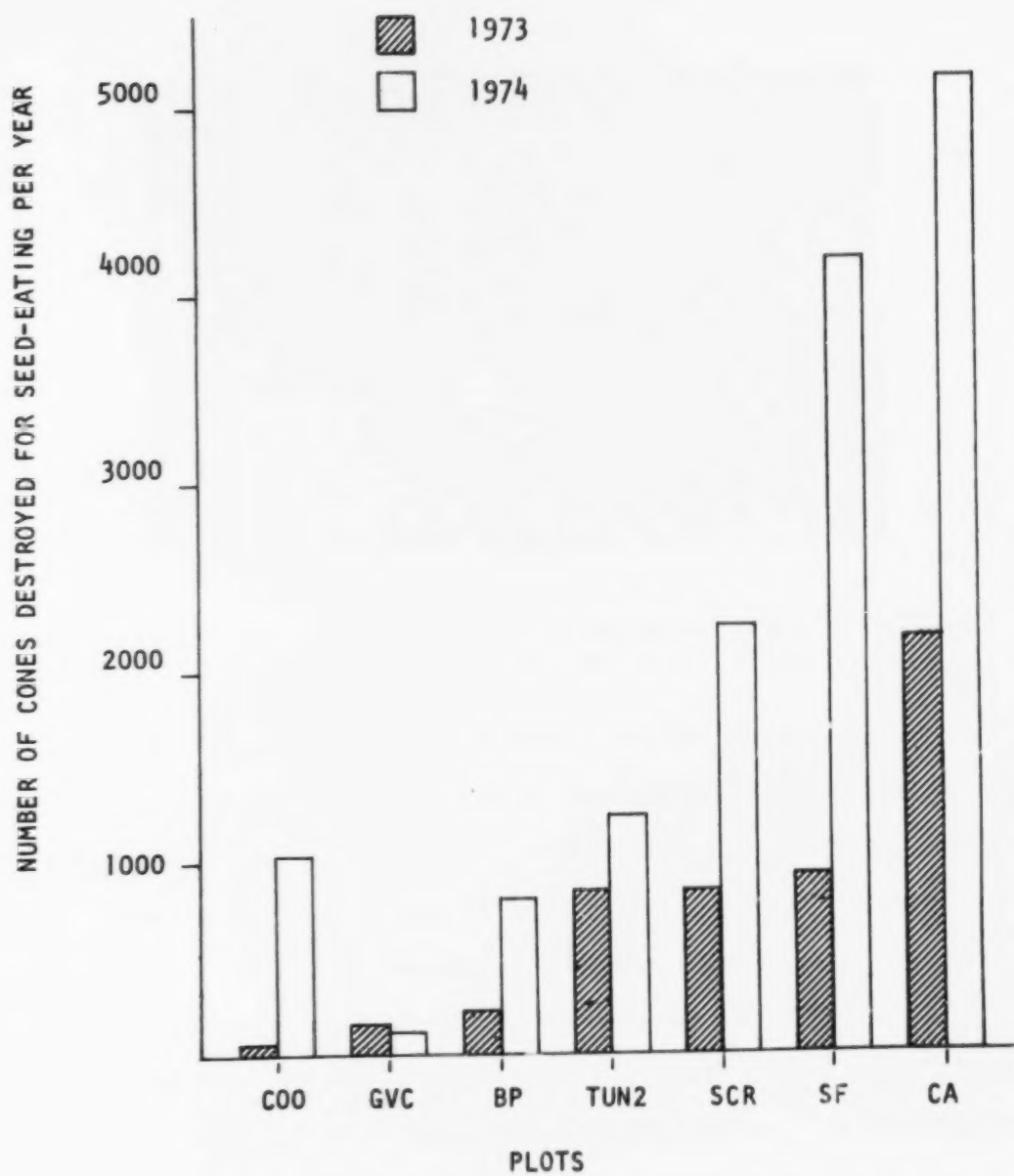


Figure 68. Comparison of cone utilization by gray squirrels in 1973 and 1974 by plot.

1974. A good example of this "favorite tree" syndrome is Jeffrey pine #1718 on the Schneider Creek plot. In 1973, 753 cones were cut; in 1974, 2034 cones were cut.

In both years, the bulk of the cone utilization occurred on only a few of the 50 overstory yellow pine trees on each plot. The cones cut from tree #1718, mentioned above, represent 85% and 90% respectively, of the total cone production for that plot in 1973 and 1974.

Gray squirrels began to cut green cones in June. In 1973, the first signs of cone-cutting appeared during the last week in June on the west side of the mountains. In 1974, workers on the west side noticed freshly cut cones by 10 June. Cone-cutting on the east side started somewhat later both years, but was underway by early July. Relatively few cones are cut during this early period through mid-July. From mid-July through mid-August the greatest amount of cone-cutting occurred. In Figure 69, we separate the three plots with the greatest amount of cone utilization from the four lowest. The salient difference between the two groups was the sustained plane of high utilization on the three heavily utilized plots during this peak period. Cone-cutting dropped off in the weeks after mid-August. On Green Valley Creek and Schneider Creek, cone-cutting ceased in late August. On all other plots, cone-cutting continued at a low level in September and October.

In total, 14,844 cones were counted on the seven study plots in 1974. All cones were cut prior to seed maturity. This large loss of seed prior to maturity may be a factor acting in concert with oxidant air pollutant injury to depress the regeneration of yellow pine. In areas unaffected by oxidants, western gray squirrels are regarded as

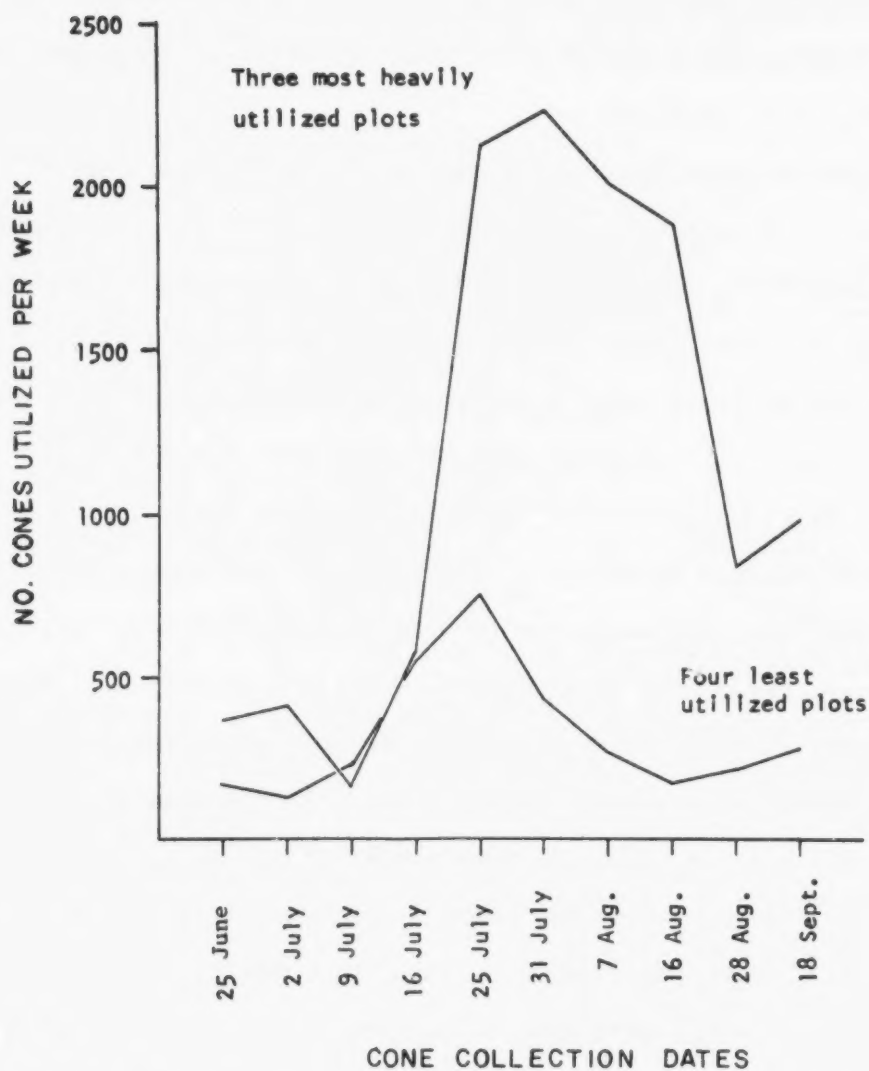


Figure 69. Extremes of weekly cone utilization by gray squirrels in 1974.

usually having limited effect on the overall regeneration potential of yellow pine (Moore, 1940; Fowells and Schubert, 1956; Larson and Schubert, 1970). Squirrel cone cutting in the oxidant injury areas

in the SBNF may be contributing to a hastening of vegetation change.

Long-Term Change in Forest Composition: Succession of the Vegetation

Continued high levels of oxidant air pollutants in the San Bernardino Mountains will affect both the rate and direction of plant succession. The vegetation subcommittee is concerned with developing a model of plant succession that can be used to predict the species composition and structure of forest stands subjected to different levels of air pollution. This model will require the cooperation of many of the investigators collecting data on other components of the ecosystem. The vegetation subcommittee's contribution to the development of this model involves the development of a conceptual (non-mathematical) model of plant succession and the field measurement of certain vegetation parameters needed to "run" the mathematical model.

Fire History ---

In order to develop a meaningful conceptual model, the vegetation subcommittee has initiated a study of plant succession following fire in the ponderosa and Jeffrey pine dominated forest types in the San Bernardino Mountains. This study is identifying variables which have influenced the rate and direction of plant succession in the past. In the summer of 1974, eighty-five plots were established in this study (Figure 1). The date of the last major fire on each plot was determined from basal fire scars on trees in or adjacent to the plots. Quadrant and line interception methods, the same as those used to characterize the vegetation on the 18 permanent plots, were used to measure the vege-

tation. The age of each tree on the plot was also determined by ring counts. Analysis of the field data has not been completed. The 85 plots may be arranged as a chronological series based on date of the last major fire. Changes in species composition and age structure along this chronological sequence will reveal the pattern of plant succession following fire in the San Bernardino Mountains.

General observations made during the previous field season suggest that fire has been a selective factor in forests of mixed species composition. White fir and incense cedar are more vulnerable to wildfire than the pine species. Similar observations have been made in other parts of California (Biswell, 1969⁷) and the southwest (Weaver, 1964). Other mortality factors operating in the San Bernardino Mountains, including air pollution, are also selective. Any model of plant succession must take into account the rate at which these mortality factors remove trees from a forest stand. Since mortality rates differ according to the age of the plants, it is necessary to know the age structure of the stand. With knowledge of the initial age structure, expected mortality rates from various factors (insects, pathogens, air pollutants, fire, herbivores), and reproductive rates (seed production and establishment), one could approach the modeling of plant succession using a modification of the life table method introduced by Leak (1970). With this approach in mind, the vegetation subcommittee has initiated a study of age structure of stands in the San Bernardino Mountains. Initially, the age structure of the 18 permanent plots was determined using ring counts on cores taken with increment borers. Tree age was also determined on the 85 fire succession plots. These data, along with

additional samples to be taken in the coming field season, will build up an important data source to be used in the modeling of plant succession.

Two age distribution curves are present in Figures 70 and 71 as examples of the variations thus far observed in the analysis of age structure. Age distribution of trees on the Dogwood plot is shown in Figure 70. These data suggest that events around the turn of the century set the stage for establishment of tree seedlings. Ponderosa pine and incense cedar became established at that time and continued to successfully establish seedlings for the next 40 years. Subsequent to the 1930's, the establishment of ponderosa pine has declined. Establishment of incense cedar continued to increase until about 1960. Since 1960, no successful regeneration of incense cedar has taken place. Establishment of black oak seedlings in the 0-9 year age class suggests this species may eventually dominate the plot, assuming the decrease in conifer regeneration is to continue.

An examination of the age distribution of the coniferous species on Sand Canyon plot suggests a pattern of continuous tree replacement (Figure 71). The periodic successful establishment of a few individuals of Jeffrey pine, white fir, and Sierra juniper have lead to a balanced all-age stand. The situation with mountain mahogany is somewhat different. In this species, there is an abundance of younger age classes, especially the 0-9 and 10-19 age classes. This may indicate an improvement in conditions for seedling establishment of mountain mahogany in recent times. The abundance of mountain mahogany seedlings impresses the observer with the species' potential for dominating the plot.

AGE DISTRIBUTION: DOGWOOD

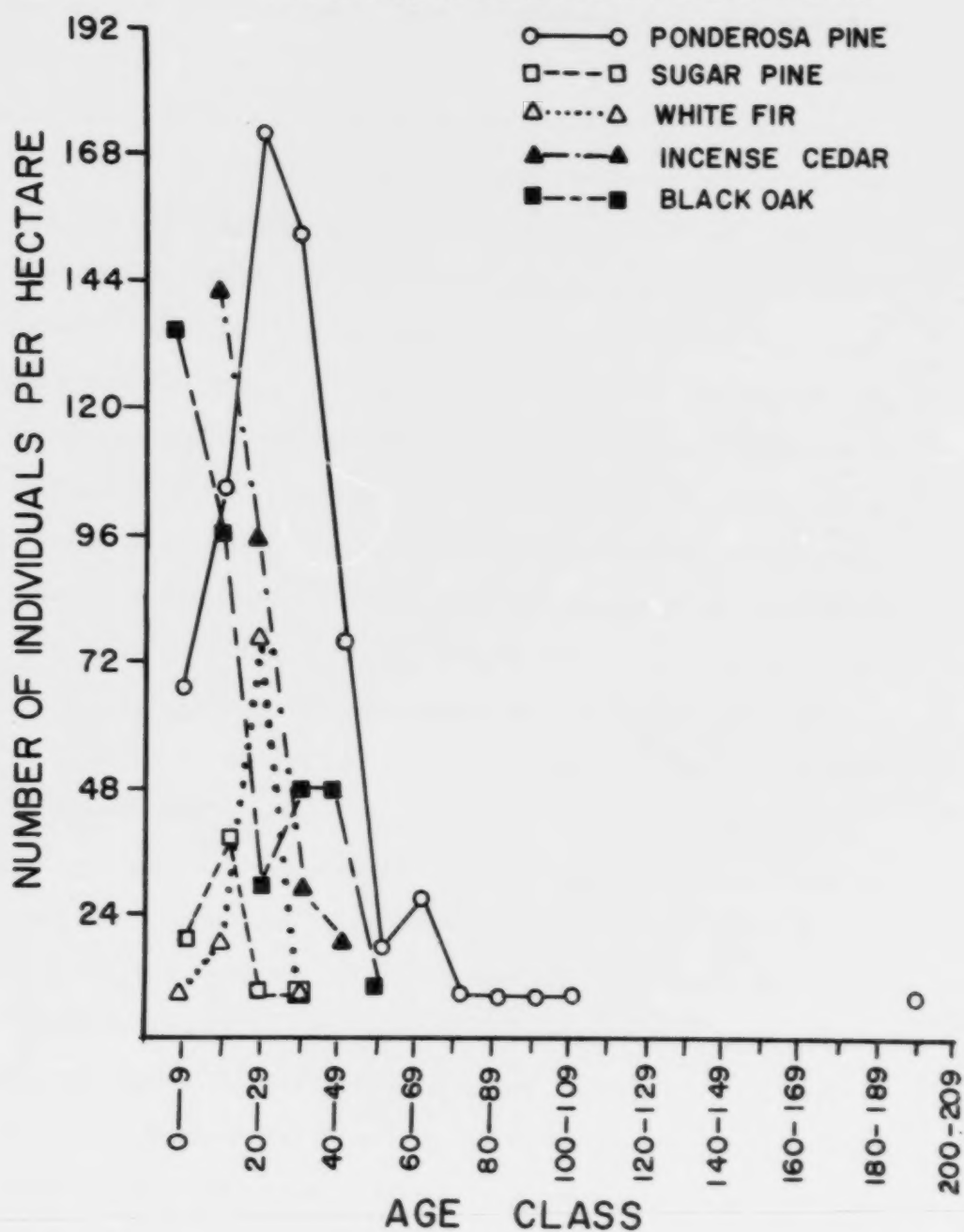


Figure 70. Age distribution for various tree species at Dogwood plot.

AGE DISTRIBUTION: SAND CANYON

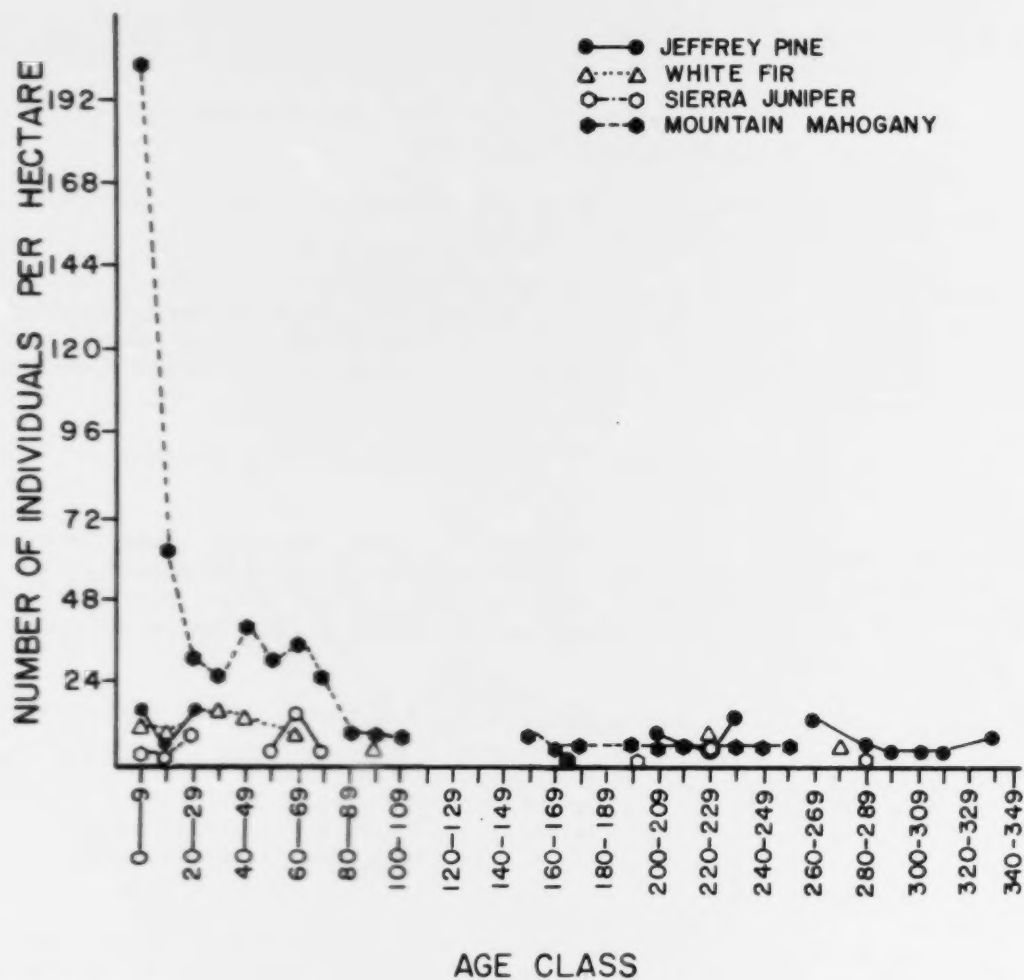


Figure 71. Age distribution for various tree species at Sand Canyon plot.

SECTION VI

REFERENCES

- American Society for Testing and Materials. 1973. Standard method of accelerated laboratory test of natural decay resistance of woods. In: Annual Book of ASTM Standards, Part 16, Designation: D-2017-71, Philadelphia, Pa. p. 642-648.
- Baxter, D.V. 1952. Pathology in Forest Practice. New York, New York: John Wiley and Sons, Inc. 601 pp.
- Bega, R. V., and R. S. Smith, Jr. 1966. Distribution of Fomes annosus in natural forests of California. Plant Dis. Repr. 50:832-836.
- Biswas, A. K. 1975. Mathematical modeling and environmental decision-making. Ecol. Modelling. 1(1):31-48.
- Biswell, H. E. 1967. Forest fire in perspective. Ann. Tall Timbers Fire Ecol. Conf., Proc. 7:43-63.
- Blumenthal, D. L., W. H. White, R. L. Peace, and T. B. Smith. 1974. Determination of the feasibility of long range transport of ozone or ozone precursors. U. S. Environmental Protection Agency, Research Triangle Park, N.C. Publication No. EPA-450/3-74-061. 92 pp.
- Boe, K. N. 1954. Periodicity of cone crops for five Montana conifers. Mont. Acad. Sci., Proc. 14:5-9.
- Boling, R. H., Jr. and J. A. VanSickle. 1975. Control theory in ecosystem management. In: Ecosystem Analysis and Prediction. Proc. SIAM-SIMS Conf., Alta, Utah, July 1-5, 1974, Levin, S.A. (ed.). Philadelphia, Society for Industrial and Applied Mathematics. p. 219-229.
- Boyce, J. S. 1961. Forest pathology. New York: McGraw-Hill Book Co. 572 pp.
- Bridges, K. W. 1974. Ecological data processing facilities: A brief review and proposal. University of Hawaii (Presented at National Park Service/Mississippi Test Facility, Bay St. Louis, Mississippi, May 23-24, 1974.) 5 pp.
- Bryson, R. A., and W. M. Wendland. 1970. Climatic effects of atmospheric pollution. In: Global Effects of Environmental Pollution, Singer, S. F. (ed.). Dordrecht, Holland: D. Reidel. p. 130-138.
- Bunnell, F. 1972. Workshop on nutrient-flux and decomposition modeling. US/IBP Tundra Biome. Inst. Anim. Resour. Ecol., Univ. Br. Columbia, Vancouver. 39 p.

- Burgess, A. 1967. The decomposition of organic material in the soil. In: Soil Biology. Burgess, A., and F. Raw, (eds.). New York: Academic Press. p. 479-492.
- Calhoun, J. B. 1959. Revised sampling procedure for the North American census of small mammals (NACSM). U.S. Department of Health, Education and Welfare, Bethesda, Maryland. Population Dynamics of Vertebrates. Release Number 10. 12 p.
- Canfield, R. 1941. Application of the line interception method in sampling range vegetation. J. Forest. 39:388-394.
- Charney, J., P. H. Stone, and W. J. Quirk, 1975. Drought in the Sahara: a biogeophysical feedback mechanism. Science. 187:434-435.
- Clements, F. E. 1905. Research Methods in Ecology. Lincoln, Nebraska: University Publishing Co. 361 p.
- Cobb, F. W., Jr., D. L. Wood, R. W. Stark, and J. R. Parmeter, Jr. 1968. Photochemical oxidant injury and bark beetle (Coleoptera: Scolytidae) infestation of Ponderosa Pine. IV. Theory on the relationship between oxidant injury and bark beetle infestation. Hilgardia. 39(6):141-152.
- Corn, M., R. W. Dunlap, L. A. Goldmunc, and L. H. Rogers. 1975. Photochemical oxidants: Sources, sinks, and strategies. J. Air Pollut. Contr. Assoc. 25:16-18.
- Crossley, D. A., Jr., and K. K. Bohnsack. 1960. Long-term ecological study in the Oak-Ridge area. 3. The oribatid mite fauna in pine litter. Ecology. 4:628-38.
- Curtis, J. T., and R. P. McIntosh. 1951. An upland forest continuum in the prairie-forest border region of Wisconsin. Ecology 32: 476-496.
- Dahlsten, D.L. 1971. Parasites, predators, and associated organisms reared from western pine beetle infested bark samples. In: Studies on the population dynamics of the western pine beetle, Dendroctonus brevicomis LeConte (Coleoptera: Scolytidae), Stark, R.W. and D.L. Dahlsten (ed.). Berkeley, University of California Division of Agricultural Sciences. p. 75-79.
- Dahlsten, D. L. 1974a. The Role of Bark Beetles, Dendroctonus spp. in the Succession of the Mixed Conifer Ecosystem, Exposed to Photochemical Air Pollutants. In: Protocol, Renewal EPA Contract 68-03-0273, Study of Effects of Oxidant Air Pollutants on a Mixed Conifer Forest Ecosystem. O.C. Taylor (editor), Statewide Air Pollution Research Center, University of California, Riverside. p. 45-59. (unpublished document.)

- Dahlsten, D. L. 1974b. The role of bark beetles, Dendroctonus spp., in the succession of the mixed conifer ecosystem exposed to photochemical air pollutants, Section III-C. In: Annual Progress Report 1973-74, for the U.S. Environmental Protection Agency, Corvallis, Or. 10 p. and Appendix.
- Dahlsten, D. L., C. J. DeMars, D. L. Rowney, and P. A. Felch. 1974. Sampling techniques and preliminary analyses for the western pine beetle in the central Sierras of California. (Unpublished manuscript, in preparation.)
- Dahlsten, D. L., and D. L. Rowney. 1974. The influence of Verticicladiella wagenerii on western pine beetle, Dendroctonus brevicomis, populations. (Unpublished progress report, Western Regional Project W-110.) 5 pp.
- Dahlsten, D.L. and F.M. Stephen. 1974. Natural enemies and insect associates of the mountain pine beetle, Dendroctonus ponderosae (Coleoptera: Scolytidae), in sugar pine. Canad. Entomol. 106: 1211-1217.
- Daubenmire, R. 1960. A seven-year study of cone production as related to xylem layers and temperature in Pinus ponderosa. Amer. Midland Nat. 64: 187-93.
- Dickinson, C. H., and G. J. F. Pugh. 1974. Biology of plant litter decomposition, Vols. I and II. New York: Academic Press. 776 p.
- Edinger, J. G. 1973. Vertical distribution of photochemical smog in the Los Angeles basin. Environ. Sci. Tech. 7:247-252.
- Edinger, J. G., M. H. McCutchan, P. R. Miller, B. C. Ryan, M. J. Schroeder, and J. V. Behar. 1972. Penetration and duration of oxidant air pollution in the south coast air basin of California. J. Air Pollut. Contr. Assoc. 22:882-886.
- Edmonds, R. L. and P. Sollins. 1974. The impact of forest diseases on energy and nutrient cycling and succession in coniferous forest ecosystems. Amer. Phytopath. Soc., Proc. 1:175-180.
- Edwards, C. A., D. E. Reichle, and D. A. Crossley, Jr. 1970. The role of soil invertebrates in the turnover of organic matter and nutrients. In: Analysis of Temperature Forest Ecosystems, Reichle, D. E. (ed.). New York: Springer-Verlag. p. 147-172.
- Environmental Protection Agency. 1970. The Clean Air Act. Washington, D.C. 56 p.
- Evans, L. S., and P. R. Miller. 1972. Ozone damage to Ponderosa Pine: A histological and histochemical appraisal. Am. J. Bot. 59: 297-304.

- Fowells, H. A., and G. H. Schubert. 1956. Seed crops of forest trees in the pine region of California. U.S. Department of Agriculture, Washington, D.C. Tech. Bull. 1150. 48 p.
- Fries, J. 1974. Growth Models for Tree and Stand Simulation. Dept. Forest Yield Research, Royal College of Forestry, Stockholm, Sweden. Research Notes No. 30. 379 p.
- Fritts, H. C. 1974. Relationships of ring widths in arid site conifers to variations in monthly temperature and precipitation. Ecol. Monogr. 44:411-440.
- Giese, R. L., R. M. Peart, and R. T. Huber. 1975. Pest Management. Science. 187(4181):1045-1052.
- Giles, R. H., Jr. 1972. Future uses of computers in environmental management. In: Proc. Workshop on Computer and Information Systems in Resources Management Decisions, Sept. 30, 1971. Stone, R. N., and K. D. Ware (eds.). Washington, D.C: U.S. Forest Service. p. 3-21.
- Glendening, G. 1952. Some quantitative data on the increase of Mesquite and cactus on a desert grassland range in southern Arizona. Ecology. 33:319-328.
- Gloria, H. R., G. Bradburn, R. F. Reinisch, J. N. Pitts, Jr., J. V. Behar, and L. Zafonte. 1974. Airborne survey of major air basins in California. J. Air Pollut. Contr. Assoc. 24:645-652.
- Goodall, D. W. 1972. Integration of shrub research effort. In: Wildland Shrubs - Their Biology and Utilization. USDA Forest Serv. Intermt. For. and Range Exp. Stn., Ogden, Utah. Gen. Tech. Rep. INT-1, 435-439.
- Graham, S.A., and F.B. Knight. 1965. Principles of Forest Entomology. 4th Edition. New York, McGraw-Hill Book Co. 417 p.
- Habeck, J. R., and R. W. Mutch. 1973. Fire-dependent forests in the northern Rocky Mountains. Quarternary Research. 3(3):408-424.
- Hampel, V. and J. Ramus. 1975. Master control - a users' manual. Lawrence Livermore Laboratory, Livermore, California. (Unpublished report.) p. 181.
- Holling, C. S. 1974. Resilience and stability of ecological systems. Ann. Rev. Ecol. System. 4:1-24.
- Holling, C. S. and A. D. Chambers. 1973. Resource Science: the nurture of an infant. Bio Science. 23(1):13-20.

- Hooven, E. F. 1969. The influence of forest succession on populations of small animals in western Oregon. In: Proc., Wildl. and Reforest. in the Pacific Northwest Sympos, Sept. 12-13, 1968, Black, H.C. (ed.) School of Forestry, Oregon State University, Corvallis, Oregon. p. 30-34.
- Hornibrook, E. M. 1939. A modified true classification for use in growth studies and timber marking in Black Hills Ponderosa Pine. J. Forest. 37:483-88.
- Horton, J. S. 1960. Vegetation types of the San Bernardino Mountains. U.S. Forest Serv., Pacific Southwest Forest and Range Expt. Sta., Berkeley, CA. Tech. Paper No. 44. 29 p.
- Innis, G. 1973. Simulation of ill-defined systems: some problems and progress. Simulation Today. 9:33-36.
- Jeffers, J. N. R. 1973. Systems modelling and analysis in resource management. J. Environ. Mgmt. 1:13-28.
- Keen, F. P. 1936. Relative susceptibility of Ponderosa Pines to bark beetle attack. J. Forest. 34:919-927.
- Kickert, R. N., A. R. Taylor, D. H. Firmage, and M. J. Behan. 1975. Fire ecology research needs identified by research scientists and land managers. Ann. Tall Timbers Fire Ecol. Conf., Proc. (in press).
- Kilgore, B. M. 1973. The ecological role of fire in Sierran conifer forests. Quat. Res. 3(3):496-513.
- Kinosian, J. R., and S. Duckworth. 1973. Oxidant trends in the South Coast air basin 1963-1972. Calif. Air Resources Board, Div. Tech Services, Sacramento. 29 p.
- Knapp, R. 1974. Handbook of Vegetation Science. The Hague, The Netherlands:W. Junk Publishers. 368 p.
- Koenig, H. E., and R. L. Tummala. 1972. Principles of ecosystem design and management. IEEE Transactions on Systems, Man, and Cybernetics. SMC-2(4):449-459.
- Kolb, J. A., and M. White. 1974. Small mammals of the San Bernardino Mountains, California. The Southwestern Naturalist 19(1):112-114.
- Kramer, P. J., and K. K. Kozlowski. 1960. Physiology of Trees. New York: McGraw-Hill, Publishing Co. 642 p.
- Kupperman, R. H., R. H. Wilcox, and H. A. Smith. 1975. Crisis Management: Some Opportunities. Science. 187(4175):404-410.

- LaChapelle, E. R. 1967. Timberline reforestation in the Austrian Alps. *Journ. For.* 65(12):868-872.
- Larson, N. M., and G. H. Schubert. 1970. Cone crops of Ponderosa Pine in central Arizona, including the influence of Abert squirrels. U.S. Forest Service. Rocky Mt. For. & Range Exp. Sta., Fort Collins, Colo. Research Paper. RM-58. 15 p.
- Lawrence, W. H. 1958. Wildlife-damage control problems on Pacific Northwest tree farms. *North Amer. Wildl. Conf. Trans.* 23:146-152.
- Leak, W. B. 1970. Successional change in northern hardwoods predicted by birth and death simulation. *Ecology*. 51:794-801.
- Levin, S. 1975. Ecosystem level concepts. In: *Ecosystem Analysis and Prediction*. Proc. SIAM-SIMS Conference, Alta, Utah, July 1-5, 1974, Levin, S. A. (ed.). Philadelphia, Society for Industrial and Applied Mathematics. p. 129-130.
- Lowry, W. P. 1966. Apparent meteorological requirements for abundant cone crops in Douglas-fir. *Forest Sci.* 12:185-192.
- Maguire, W. P. 1956. Are Ponderosa Pine cone crops predictable? *J. Forest.* 54:778-9.
- Mar, B. W. 1974. Problems encountered in multidisciplinary resources and environmental simulation models development. *J. Environ. Manag.* 2:83-100.
- McBride, J. R. 1974. Annual report of the vegetation subcommittee for the fiscal year ending June 15, 1974, Section III-B. In: *Annual Progress Report 1973-74, for the U.S. Environmental Protection Agency, Corvallis, Or.* 22 p.
- McCutchan, M. H., and M. J. Schroeder. 1973. Classification of meteorological patterns in southern California by discriminant analysis. *J. Appl. Meteorol.* 12:571-577.
- Millar, C. S. 1974. Decomposition of coniferous leaf litter. In: *Biology of Plant Litter Decomposition*. Dickinson, C. M., and G. J. F. Pugh (eds.). New York: Academic Press. p. 105-128.
- Miller, J. M., and F. P. Keen. 1960. Biology and control of the western pine beetle. A summary of the first fifty years of research. U.S. Department of Agriculture Forest Service, Washington, D.C. Misc. Publ. No. 800. 381 p.
- Miller, P. R. 1973a. Oxidant-induced community change in a mixed conifer forest. In: *Air Pollution Damage to Vegetation*, Nagele, J. A. (ed.). *Advances in Chem. Ser.*, 122:101-117.

- Miller, P. R. 1973b. Oxidant damage to conifers on selected study sites, 1972. In: Oxidant Air Pollutant Effects on a Western Coniferous Forest Ecosystem. Task C. Report: Study Site Selection and Verification Data on Pollutants and Species. Taylor, O. C. (ed.). U.S. Environmental Protection Agency, Corvallis, Or. Section III. 20 p.
- Miller, P. R. 1974. Environmental monitoring and measurement of oxidant damage to vegetation in the San Bernardino Mountains, Section A. In: Annual Progress Report 1973-1974, for the U.S. Environmental Protection Agency, Corvallis, Or. 12 p.
- Miller, P. R. 1975. Personal communication.
- Miller, P. R., and A. A. Millecan. 1971. Extent of oxidant air pollution damage to some pines and other conifers in California. Plant Dis. Repr. 55:555-559.
- Miller, P. R. and H. P. Milligan. Ozone susceptibility of western conifers. (In preparation.)
- Miller, P. R., J. R. Parmeter, Jr., B. H. Flick, and C. W. Martinez. 1969. Ozone damage response of Ponderosa pine seedlings. J. Air Pollut. Contr. Assoc. 19:435-438.
- Minnich, R. C., L. W. Bowden, and R. W. Pease. 1969. Mapping montane vegetation in southern California. -- Status Report 3, Contract No. 14-08-0001-10674. U.S. Department of the Interior, Tech. Report 3. Dept. of Geography, Univ. Calif., Riverside, Ca. 40 p.
- Mirov, N. T. 1967. The Genus Pinus. New York, Ronald Press Co. 602 p.
- Moore, A. W. 1940. Wild animal damage to seed and seedlings on cut-over Douglas-fir lands of Oregon and Washington. U.S. Department of Agriculture, Washington, D.C. Tech. Bull. No. 706. 28 p.
- Mukammal, E. I. 1965. Ozone as a cause of tobacco injury. Agr. Meteorol. 2:145-165.
- National Academy of Sciences, 1974. U.S. participation in the international biological program. U.S. National Committee for the International Biological Program, Washington, D.C. Report No. 6. 165 p.
- National Primary and Secondary Ambient Air Quality Standards. 1971. Federal Register. 36:8186-8201.

- National Science Board. 1972. Terrestrial ecosystems. In: Patterns and Perspectives in Environmental Science. Washington, D.C.: National Science Foundation. p. 277-315.
- Noy-Meir, I. 1973. Desert ecosystems: Environment and producers. *Ann. Rev. Ecol. System.* 4:25-51.
- Odum, E. P. 1971. Fundamentals of Ecology. Philadelphia: W. B. Saunders Co. 574 p.
- Patton, D. R. 1975. Abert squirrel cover requirements in southwestern ponderosa pine. *USDA For. Serv. Res. Pap.* RM-145. 12 p.
- Pearson, G. A. 1923. Natural reproduction of western yellow pine in the southwest. U.S. Department of Agriculture, Washington, D.C., *Bull.* 1105. 143 p.
- Price, D. W. 1973. Abundance and vertical distributions of microarthropods in the surface layers of a California pine forest soil. *Hilgardia.* 42(4):121-148.
- Puritch, G. S. 1972. Cone production in conifers. Pacific Forest Research Centre, Canadian Forestry Serv., Dept. Environment, Victoria, British Columbia. Information Report (BC-X-65). 94 p.
- Reed, K. and R. H. Waring. 1974. Coupling of environment to plant response: a simulation model of transpiration. *Ecology.* 55(1):62-72.
- Roeser, J., Jr. 1941. Some aspects of flower and cone production in Ponderosa Pine. *J. Forest.* 39:534-536.
- Ryan, B. C. 1974. A mathematical model for diagnosis and prediction of surface winds in mountainous terrain. Ph.D. dissertation, Department of Geography, University of California, Riverside. 135 pp.
- Smith, W.H. 1970. Tree Pathology: A short introduction. New York, New York: Academic Press. 309 p.
- Smith, W. H. 1974. Air pollution-effects on the structure and function of the temperate forest ecosystem. *Environ. Pollut.* 6:111-129.
- Soil Survey Staff, Soil Taxonomy. U.S. Department of Agriculture Soil Conservation Service. (In preparation.)
- Sollins, P., R. H. Waring, and D. W. Cole. 1974. A systematic framework for modeling and studying the physiology of a coniferous forest ecosystem. In: Integrated Research in the Coniferous Forest Biome. *Bulletin No. 5.* Waring, R. H. and R. L. Edmonds (eds.). University of Washington, Seattle, Wash. p. 7-20.

- Stage, A. R. 1973. Prognosis model for stand development. USDA For. Serv. Intermountain Forest and Range Expt. Sta., Ogden, Utah. Res. Pap. INT-137. 32 p.
- Stark, R. W., and D. L. Dahlsten, editors. 1970. Studies on the Population Dynamics of the Western Pine Beetle, Dendroctonus brevicomis LeConte (Coleoptera: Scolytidae). Univ. of California, Div. of Agric. Sciences, Berkeley. 174 p.
- Stark, R. W., P. R. Miller, F. W. Cobb, Jr., D. L. Wood, and J. R. Parmeter. 1968. Photochemical oxidant injury and bark beetle (Coleoptera: Scolytidae) infestation of Ponderosa Pine. I. Incidence of bark beetle infestation in injured trees. *Hilgardia*. 39(6):121-126.
- Taylor, O. E., (editor). 1974. Oxidant Air Pollutant Effects on a Western Coniferous Forest Ecosystem. Annual Progress Report 1973-74. U.S. Environmental Protection Agency, Corvallis, Or. 116 p.
- Thompson, W. G. 1940. A growth rate classification of southwestern Ponderosa Pine. *J. Forest*. 38:547-53.
- U.S. Forest Service. 1973. Timber Inventory Map, U.S. Department of Agriculture, San Bernardino National Forest, San Bernardino, California.
- Van Dyne, G. M. 1972. Organization and management of an integrated ecological research program. In: *Mathematical Models in Ecology*, Jeffers, J. N. R. (ed.). London, Blackwell Scientific Publications. 398 p.
- Weaver, H. 1964. Fire and management problems in Ponderosa Pine. *Ann. Tall Timber Fire Ecol. Conf., Proc.* 3:61-79.
- Wellner, C. A. 1970. Fire history in the northern Rocky Mountains. *Symp. Role of Fire in the Intermountain West, Proc. Intermountain Res. Council, Missoula, Mont.* 42-64.
- White, M. 1974. Effect of oxidant air pollutants on the vertebrate animal community, Section 111-K. In: *Annual Progress Report 1973-74, for the U.S. Environmental Protection Agency, Corvallis, Oregon*. 22 p.
- White, M., and J. A. Kolb. 1973. A survey of terrestrial vertebrates in the mixed conifer portion of the San Bernardino Mountains. In: *Oxidant Air Pollutant Effects on a Western Coniferous Forest Ecosystem. Task C: Study site selection and verification data on pollutants and species*. Taylor, O. C. (ed.). U.S. Environmental Protection Agency, Corvallis, Or. Section VII. 54 p.

Wiegert, R. G. 1975. Simulation models of ecosystems. *Ann. Rev. Ecol. System.* 6:311-338.

Wood, D. L. 1971. The impact of photochemical air pollution on the mixed conifer forest ecosystem arthropods. In: Oxidant air pollutant effects on a western coniferous forest ecosystem. Task B. Report: Historical background and proposed systems study of the San Bernardino Mountain Area. U.S. Environmental Protection Agency, Corvallis, Or. Section C. 26 p.

Woodwell, G. M. 1970. Effects of pollution on the structure and physiology of ecosystems. *Science.* 168:429-433.

Woodwell, G. M. 1975. The threshold problem in ecosystems. In: Ecosystem Analysis and Prediction. Proc. SIAM-SIMS Conference, Alta, Utah, July 1-5, 1974. Levin, S. A. (ed.). Philadelphia, Society for Industrial and Applied Mathematics. p. 9-21.

SECTION VII

GLOSSARY

(An underlined word in a definition implies that this word is defined in another part of this glossary).

AAH - Ambient air house; a greenhouse experiment to evaluate tree growth in which ambient air was drawn into the house by fans.

AAO - Ambient air outdoors; used in reference to the outdoor control in an experiment on tree growth.

Abscission - Act or process causing leaves or needles to detach from the stem and fall to the ground; it occurs following advanced oxidant injury to leaves.

Accumulated Oxidant Dose - The sum of all the hourly average concentrations of total oxidant for any specified period, e.g., a month or a growing season, expressed as micrograms per cubic meter -hours ($\mu\text{g}/\text{m}^3$ -hrs).

Agar Media - A gelatinous nutrient substrate for growing microorganisms in the laboratory.

Alluvial - Deposited by running water, as soil material deposited during a flood.

Ambient Air - Air surrounding a given location; the outside air.

APCD - Air pollution control district, a county agency.

Attack - The point on a tree where the female bark beetle (Dendroctonus spp.) bores through the bark to feed and begin egg laying.

Available Water Storage Capacity - The total amount of water which a soil is capable of holding and which the plants can use.

Background Concentration (of ozone) - The world-wide background or natural concentration of tropospheric ozone injected downward from the stratosphere or formed by photochemical reactions in the troposphere; generally considered to be $59 \mu\text{g}/\text{m}^3$ (0.03 ppm).

Basal Area - The area of cross section of a tree, expressed in square meters, and referring to the section at breast height.

Basal Fire Scars - Area of charred wood at the base of a living tree caused by a wildfire.

Bioindicator - Biological organisms which have specific sensitivity to a single pollutant and thus are useful as indicators for the presence of that pollutant.

Biomass - The total quantity at a given time of living organisms of one or more species per unit of space (species biomass), or of all the species in a community (community biomass).

Bole - The trunk or stem of a tree.

Bolt - A relatively small cylindrical section cut from the stem of a tree.

Branch Order - The arrangement of branches on a tree. The following terms are used to identify branches according to their order: main stem is referred to as the leader; any branch growing out of the leader is a first order branch; any branch growing out of a first order branch is a second order branch; any branch growing out of a second order branch is a third order branch, etc.

Cation - An ion which is positively charged in solution; typical cations in soils are potassium, sodium, calcium and magnesium (K^+ , Na^+ , Ca^{++} , and Mg^{++}).

Chlorotic Mottle - Irregular, diffuse patterns of yellow areas interspersed with normal green tissue.

Climax - Vegetation existing in a relatively stable equilibrium with its environment and with good reproduction of the dominant plants.

Codominant - Trees that share dominance of the canopy of a forest stand.

Colluvial - Deposited at least in part as a result of gravitational movement of material; occurs at the base of slopes and is sometimes stony or rubbly.

Colonization - Spread of a fungus throughout a substrate.

Complement - See leaf complement and needle complement.

Conidial - Of or pertaining to conidia which are asexual spores of many fungi.

Cores - Cylindrical samples of wood removed from a tree with a tool known as an increment borer.

Cover - The ground area covered by the individuals of one species.

Crown - The portion of a tree containing limbs, branches and foliage.

Crown Drip - Liquid which falls to the ground under the crown of a tree or other plant during precipitation or dew-formation onto the crown.

Crumb Structure - Same as granular structure except that the soil aggregates are relatively porous; common in the surface of forested soils.

Damping-off - The lethal effect of certain fungi on germinating seeds or seedlings.

Data Form - A standardized form upon which a certain type of information is recorded, mostly in the field.

Data Set - An identifiable complete unit of information composed of several individual entries.

DBH - Diameter of the trunk of a tree measured at breast height above the ground surface.

Debug (. . .computer program) - The identification and elimination of problematical errors in a computer program so that the computer may perform the intended functions.

Density - Number of individuals per unit area.

Dilution Plating - A known weight of humus or mineral soil is suspended and diluted in sterile distilled water; a portion of the suspension is swirled in water agar medium; developing fungal colonies are identified and counted.

Direct Plating - A known weight of litter or fermentation zone material is distributed evenly over the surface of water agar medium; developing fungal colonies are identified and counted.

Dose - A measured concentration of a toxicant for a known duration of time to which vegetation is exposed.

Duff - A collective term that includes the litter layer (fresh or slightly altered organic matter), fermentation layer (partially decomposed organic matter), and humus layer (amorphous organic matter) of the soil.

Eclosion - The emergence of the adult insect from the pupa or the act or process of hatching from the egg.

Ecosystem - A level of biological organization that includes the total array of plant and animal life in an environment and also the matter which cycles through the system and the energy used to power the system.

Egg Niche - A small notch chewed by the adult bark beetle in the side of a gallery into which an egg is deposited.

Epidemiology - The study of spread or increase of disease.

Exchangeable Cation - A cation which is held mainly by the colloidal portion of the soil (clay and organic matter) which is not soluble in pure water but is easily exchanged with the cation of a neutral salt solution.

FAH - Filtered air house; used in reference to the greenhouse treatment in an experiment on tree growth in which filtered air (ozone removed) was forced into the house by fans.

Fascicle - A bundle of 1-5 needle leaves all originating from a common growth point; a characteristic of the foliage of pine trees.

Forest Floor - All dead vegetable matter or organic matter resting on the surface of the mineral soil, including leaves, branches, needles and humus not incorporated into the mineral soil; under forest vegetation.

Frass - A combination of boring dust and excrement or feces produced by feeding insects.

Gallery (length) - The tunnel created by adult bark beetles as they feed and deposit eggs in the phloem layer of a tree.

Granular Structure - Soil aggregates generally spheroidal in shape and less than 10 mm in diameter and relatively nonporous.

Gruss - Any rock that is granulated but not decomposed by weathering. Partially weathered granitic rocks are often gruss.

Herbaceous - Refers to plants that die back to the ground each year; for example, grasses and forbs are distinct from shrubs and trees in this regard.

Host - The plant, or animal, on, or in which a parasite exists.

Human Welfare Effects - Includes, but is not limited to, effects on soils, water, crops, vegetation, man-made materials, animals, wildlife, weather, visibility, and climate, damage to and deterioration of property, and hazards to transportation, as well as effects on economic values and on personal comfort and well-being. (Clean Air Act, 1970).

Hypa - One of many cellular filaments making up the thallus of a fungus.

Importance Value - A measure of the degree to which a species occurs in a vegetation type and exerts influence on the microclimate of the type.

Inclusion Type - This refers to images in the x-rays of the bark samples that are categorized by form and developmental stage of the insect inclusions. There are six categories used in this study.

Infection - Establishment of a physiological relationship between a host and pathogen.

Instar - The period or stage between molts in the larva, numbered to designate the various periods; e.g., the first instar is the stage between the egg and the first molt, etc.

Internode - The portion of a woody stem produced in a single growing season.

Isolate - The product of culturing a small portion of a microorganism to yield a new individual.

Lachrymator - An atmospheric chemical compound which induces tears to run from the human eyes, and possibly from the eyes of various animals.

Larva - The young individuals in an insect population, which are due to undergo changes in their structural form.

Larval Mine - The small tunnels created by bark beetle larvae as they feed in the phloem or bark of a tree, generally perpendicular to the parent adult gallery.

Leaf Complement - A subjective evaluation of numbers of leaves present on all living branches of an oak tree as average, or less than average, for the stand.

Life Table - Similar to the actuarial tables kept by life insurance companies for humans. As adapted for insects, it is a convenient method to account for mortality during each developmental stage of an insect.

Line Interception Method - The sampling of vegetation by recording the plants intercepted by a measured line placed close to the ground, or by vertical projection on the line.

Loam - A textural class of soil containing 7 to 27 percent clay, 28 to 50 percent silt, and 23 to 52 percent sand.

Main Leader - The central trunk of a tree, usually refers to the youngest or tip portion.

Metamorphic Rock - Rock formed from pre-existing rock by mineralogical, chemical and structural alteration due to geologic processes originating within the earth.

Mesoscale Meteorological Patterns - A scale of observation of meteorological elements, namely winds and temperatures, which is intermediate between very local observations such as up-canyon or down-canyon breezes in a single canyon and the synoptic scale observations describing conditions over a broad area like the southwestern United States. The density of observing stations for mesoscale interpretation is typically 50 miles apart.

Micrograms Per Cubic Meter, $\mu\text{g}/\text{m}^3$ - A measure of the concentration of a pollutant in micrograms per cubic meter of air at standard temperature and pressure.

Minimum Moisture Content - Measured soil water content at the driest period of the year; corresponds approximately to permanent wilting point.

Mixed Brood - A situation in bark beetle infested trees in which more than one species of bark beetle offspring is present in the same tree.

Model - A description of the system which it represents.

Molt - The process of certain organisms shedding their outer covering, to be succeeded by new growth.

Mortality - A standing tree whose current year buds are dead; a coniferous tree may be defoliated without being dead.

Needle Complement - The total number of needle fascicles retained on each branch internode, which were formed in any one growing season.

Needle Injury Score - The score or index is the sum of individual ratings for chlorotic mottle, necrosis and abscission, each on a scale of 0 to 4. The score, or index, may be as high as 12 for a single annual needle complement. Scores for current and one-year-old needle complements are often added together; this scoring procedure is adequate for seedlings and small saplings only.

Necrosis - An advanced stage of tissue injury indicated by brown, dead tissue, involving all or parts of a leaf or needle; necrosis develops following chlorotic mottle, especially in older leaf tissues.

Oviposition - the act of depositing eggs.

Oxidant Air Pollutants - Gas phase molecules and compounds capable of oxidizing a reference substance, namely the liberation of iodine from potassium iodide solutions; these include ozone (more than 90 percent) and smaller amounts of nitrogen dioxide and peroxyacetyl nitrate and its homologs, e.g., propionyl and butyrl.

Paradigm - The basic pattern underlying the functioning of a system.

Parameter - A characteristic which can be easily quantified.

Parasitoid - An insect, generally a wasp or fly, which lays its own eggs on the eggs, larvae, or adults of other species of insects (hosts) so that the larvae may develop by feeding within or upon the body of the host.

Particle Size Distribution - See soil texture.

Pathogen - Organism capable of causing disease.

Pathogen Type - An organism, not usually considered a pathogen, which behaves like a pathogen under special circumstances.

Pathophysiology - The altered metabolic state of pathogen infected, or toxicant injured tissues.

Permanent Wilting Point - The soil moisture content at or below which plants can absorb water only very slowly or not at all; sunflower used as a test plant wilts and does not recover over night.

pH (soil) - A measure of the acidity or alkalinity of a soil expressed as the negative logarithm of the hydrogen-ion activity of the soil. The general range of soil pH is 4.0 (very strongly acid), 7.0 (neutral), 10.0 (strongly alkaline).

Phenology - The study of the time of appearance of characteristic periodic events in the life cycles of organisms in nature.

Phloem - The complex tissue of higher plants which forms a spongy layer between the protective outer layer and the inner structurally supportive portion. Its function is to transport food materials.

Photosynthetic Capacity - The ability of a plant to convert inorganic carbon in the air, from carbon dioxide, into organic carbon molecules in a given environment.

Phytotoxicant - Any chemical agent that causes injury to plants.

Pitch Tube - A small resinous tube projecting from the bark of a tree as a result of a beetle boring into the tree. A successful attack is indicated by frass in the resin while an unsuccessful attack produces a pitch tube without frass.

Plot - An area of land surface within which vegetation, soil, and animal life is periodically inventoried and studied for determining dynamic interactions among them. In this study, 18 plots were delineated on the ground during 1972 in the San Bernardino Mountains. The range of individual plot area sizes runs from 0.2 ha to 1.2 ha.

Pollinator - An organism, usually an insect, which carries pollen from one flower to another.

ppb - Parts by weight, or volume, of pollutant per billion parts by volume of air (usually refers to volume of pollutant if not so stated).

pphm - Parts by weight, or volume, of pollutant per hundred million parts by volume of air (usually refers to volume of pollutant if not so stated).

ppm - Parts by weight, or volume, of pollutant per million parts by volume of air; it usually refers to volume of pollutant if not so stated.

Pupal Cell - A cavity in the bark or phloem created during the final feeding of the larvae of bark beetles and in which the larvae go into a non-feeding, and often immobile, transformed stage of development.

Quadrat - A sampling area 0.1 m square used to sample herbaceous vegetation.

r-Value - The coefficient of correlation between a dependent and an independent variable. When there is no association between two variables, the correlation coefficient is 0; when there is perfect positive association, the coefficient is +1; and when there is perfect negative association, the coefficient is -1.

Rearing - Raising insects in the laboratory. This allows insects to complete their development to the adult stage before being collected and identified. Immature insects are difficult to identify so this is an important procedure.

Rearing Carton - A paper ice cream carton with a glass vial attached to the lid. It is used to capture insects as they emerge from the bark samples. The insects are attracted to light and fall into the glass vial.

Ring Count - A method used to determine tree age by counting annual growth rings of the bole, usually at DBH.

Sanitation Salvage - A forest management technique with the objective of periodic removal of ponderosa and Jeffrey pines judged to have reduced vigor and to be more susceptible to fatal attack by bark beetles; the selection and cutting process is repeated every 10 years.

Sapling - A tree that is more than one meter in height and less than 10 cm in diameter at breast height.

Saprophyte - An organism utilizing an organic source of food which is dead.

Senescence - The combined processes by which leaves or needles on a tree age, and undergo abscission.

Simulation - The process of using a dynamic model on an electronic computer to mimic the functioning of a system or process by repeated step-by-step solution of the equations describing the system.

Soil Bulk Density - The mass of dry soil per unit volume of soil in its natural state which may be moist at the time the volume is determined.

Soil Core - A cylindrical sample of soil, usually circular in horizontal cross section.

Soil-dilution Assay - See dilution plating.

Soil Moisture Regime - The variation of soil moisture content throughout the soil through an entire year.

Soil Texture - A classification of soil material based upon particle size distribution of the mineral grains in the soil, the relative proportions of sand, silt, clay and gravel.

South Coast Air Basin (SCAB) - One of the five principal airsheds (atmospheric basins) in the State of California and partially located within the six counties of Santa Barbara, Ventura, Los Angeles, San Bernardino, Orange and Riverside.

Species Composition - The relative percentage of the total number of individuals in a vegetation type represented by a certain species.

Species Dominance - The degree of influence a species exerts over a vegetation type.

Spore - A reproductive body capable of developing into a new individual fungus thallus.

Subsoil - A general term for soil material from about 25 to 100 cm depth below the surface, although these depths may vary considerably.

Succession - The replacement of one vegetation type by another.

Synoptic meteorological patterns - Typically a description of air pressure patterns at the surface and at higher elevations over a broad area (see mesoscale meteorological patterns). Synoptic scale stations are usually more than 100 miles apart, e.g., Los Angeles, California and Tonapah, Nevada.

System - A set of elements together with relations among the elements and among their states.

Systems Ecology - The application of the philosophy and techniques of systems analysis to ecological problems.

Temperature Inversion - When air temperature decreases from the surface up at a rate greater than 5.5 F per 1,000 ft. or 1.0 C per 100 m, there is pronounced vertical mixing. But if the temperature increases with height, vertical air movements are suppressed. This temperature profile is "inverted" from the normal condition and it is a temperature inversion. Air pollutants are trapped near the ground by temperature inversions.

Terminal Shoot - The uppermost section of the main leader of a tree.

Thallus - The vegetative structures comprising body of lower plant forms, for example, fungi.

Troposphere - The layer of air extending 7 miles above the earth's surface and containing 80 percent of the total atmospheric mass.

Vegetation Type - A plant community of definite floristic composition, presenting a uniform physiognomy and growing in uniform habitat conditions.

Volumetric Water Content - The volume water content of soil per unit volume of soil; expressed as percent by volume.

Water Balance - A complete accounting of the soil moisture regime; water gains and losses from, and to, the atmosphere, and losses to runoff and deep percolation into the groundwater system.

SECTION VIII

APPENDIX

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Appendix A. AMBIENT AIR QUALITY STANDARDS

California Standards			National Standards ^a		
Pollutant	Averaging Time	Concentration ^b	Method ^c	Primary ^{b,d}	Secondary ^{b,e} Method ^f
Photochemical Oxidants (Corrected for NO)	1 hour	0.10 ppm (200 µg/m ³)	Neutral Buffered Potassium Iodide	160 µg/m ³ (0.08 ppm)	Same as Primary Std. Chemiluminescent Method
Carbon Monoxide	12 hour	10 ppm (11 mg/m ³)	Non-dispersive Infrared Spectroscopy	-	Same as Primary Std. Non-Dispersive Infrared Spectroscopy
	8 hour	--		10 mg/m ³ (9 ppm)	
	1 hour	40 ppm (46 mg/m ³)		40 mg/m ³ (35 ppm)	
Nitrogen Dioxide	Annual Average	--	Saltzman Method	100 µg/m ³ 0.05 ppm	Proposed: Modified J-H Saltzman (O ₃ corr.) Chemiluminescent
	1 hour	0.25 ppm (470 µg/m ³)		--	

Appendix A. AMBIENT AIR QUALITY STANDARDS (Continued)

NOTES:

- a National standards, other than those based on annual averages or annual geometric means, are not to be exceeded more than once per year.
- b Concentration expressed first in units in which it was promulgated. Equivalent units given in parentheses are based upon a reference temperature of 25C and a reference pressure of 760 mm of mercury. All measurements of air quality are to be corrected to a reference temperature of 25C and a reference pressure of 760 mm of Hg (1,013.2 millibar); ppm in this table refers to ppm by volume, or micromoles of pollutant per mole of gas.
- c Any equivalent procedure which can be shown to the satisfaction of the Air Resources Board to give equivalent results at or near the level of the air quality standard may be used.
- d National Primary Standards: The levels of air quality necessary, with an adequate margin of safety, to protect the public health. Each state must attain the primary standards no later than three years after that state's implementation plan is approved by the Environmental Protection Agency (EPA).
- e National Secondary Standards: The levels of air quality necessary to protect the public welfare from any known or anticipated adverse effects of a pollutant. Each state must attain the secondary standards within a "reasonable time" after implementation plan is approved by the EPA.
- f Reference method as described by the EPA. An "equivalent method" of measurement may be used but must have a "consistent relationship to the reference method" and must be approved by the EPA.
- g Corrected for SO₂ in addition to NO₂.

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Appendix B. CLASSIFICATION OF SOILS OF MAJOR PLOTS IN THE
SAN BERNARDINO MOUNTAINS.

<u>Plot</u>	<u>Soil Series</u>	<u>Classification: Soil Taxonomy (1973)</u>
Lake Arrowhead Region		
Dogwood	Shaver	Pachic Ultic Haploxeroll, coarse loamy, mixed, mesic
	Unnamed-1	See below
Sky Forest	Shaver	See above
	Unnamed-1	Pachic Ultic Argixeroll, fine loamy, mixed, mesic
NE13	Shaver	See above
S22	Crouch	Ultic Haploxeroll, coarse loamy, mixed, mesic
UC Conf. Cen.	Unnamed-2	Ultic Argixeroll, fine loamy, mixed, mesic
NW Camp Paivika	Shaver	See above
Breezy Point	Shaver	See above
Tunnel Two	Stump Springs	Ultic Haploxeralf, fine loamy, mixed, mesic
East of Lake Arrowhead Region		
Camp O-Ongo		
25M, 13 M R.		
76M, 7 M R.	Unnamed-3	Typic Xerorthent, coarse loamy, mixed, frigid
58M, 11 M L.	Unnamed-4	Entic Xerumbrept, coarse loamy, mixed, frigid
142M, 2 M R.	Unnamed-5	Pachic Xerumbrept, coarse loamy, mixed, frigid

Appendix B. CLASSIFICATION OF SOILS OF MAJOR PLOTS IN THE
SAN BERNARDINO MOUNTAINS. (Continued)

<u>Plot</u>	<u>Soil Series</u>	<u>Classification: Soil Taxonomy (1973)</u>
Green Valley Creek		
(Valley)	Unnamed-6	Entic Xerumbrept, sandy, mixed, mesic
(Hill)	Unnamed-7	Typic Xerorthent, sandy, mixed, mesic
Snow Valley 0-156M	Heitz	Lithic Xeropsamment, mixed, frigid
156-249M	Chiquito	Entic Xerumbrepts, coarse loamy, mixed, frigid
NE GREEN VALLEY		
0- 60M	Corbett	Typic Xeropsamment, mixed, frigid
60-175M	Heitz	Lithic Xeropsamment, mixed, frigid
Big Bear Lake Region		
Bluff Lake	Gefo Variant	Typic Xerombrupt, sandy, mixed, frigid
	Ducey Variant	Typic Xerumbrept, coarse loamy, mixed, frigid
Holcomb Valley	Domingo	Typic Argixeroll, fine loamy, mixed, mesic
	Unnamed-10	Typic Haploxeroll, coarse loamy, mixed, mesic

Appendix B. CLASSIFICATION OF SOILS OF MAJOR PLOTS IN THE
SAN BERNARDINO MOUNTAINS. (Continued)

<u>Plot</u>	<u>Soil Series</u>	<u>Classification: Soil Taxonomy (1973)</u>
Sand Canyon		
(Granite area)		
	Heitz	Lithic Xeropsamment, mixed, frigid
	Unnamed-8	Lithic Xerorthent, coarse loamy, mixed, acid, frigid
	Delleker Variant	Typic Haploxeralf, fine loamy, mixed, frigid
	Unnamed-3	Typic Xerorthent, coarse loamy, mixed, frigid
(Mixed alluvial area)		
	Unnamed-9	See above
	Gefo Variant	Typic Xerumbrepts, sandy, mixed, frigid
Santa Ana Canyon Region		
Camp Angelus	Cahto Variant	Pachic Ultic Haploxeroll, loamy-skeletal, mixed, mesic
	Unnamed-10	Typic Haploxeroll, coarse loamy, mixed, mesic
Schneider Creek	Crouch Variant	Ultic Haploxeroll, sandy, mixed, mesic
Heart Bar	Gearson Variant	Typic Haploxeroll, sandy, mixed, frigid
	Unnamed-11	Typic Xerochrept, sandy, mixed, frigid

Appendix C. PARTICLE SIZE DISTRIBUTION AND pH OF REPRESENTATIVE SOIL
SAMPLES FROM MAJOR STUDY PLOTS.

Plot-site	Depths	Sand 2-.05 mm (%)	Silt .05-.002 mm (%)	Clay <.002 mm (%)	Fine Gravel 2-12mm (%)	Gravel >12mm (%)	pH
	(cm)						
Dogwood-1	0-23	71.6	20.3	8.1	29.0	1.3	5.83
	77-99	62.7	19.1	18.1	62.3	0.6	5.73
	122-141	69.2	19.6	11.2	38.3	0.4	5.59
Dogwood-2	0-19	72.8	20.7	6.6	21.7	0.0	6.05
	112-126	67.7	16.9	15.4	51.6	2.7	5.53
	173-198	74.6	20.5	4.8	28.0	0.3	5.52
Dogwood-3	0-25	69.2	18.2	12.6	42.2	0.9	5.40
	29-112	71.4	16.7	12.0	42.8	1.3	5.70
	119-140	69.1	14.2	16.7	42.3	0.6	5.50
S 22	0-20	74.0	18.1	7.9	0.2	4.9	6.75
	41-58	74.2	18.1	7.6	7.0	5.0	5.80
	79-99	77.5	14.8	7.7	6.9	0.6	5.33
NE 13	0-24	74.7	15.8	9.5	29.2	7.7	6.28
	109-133	74.2	13.8	12.0	36.8	0.0	5.50
	246-272	78.3	15.6	6.1	37.1	0.4	5.21
UC Conf. Cen.	0-25	69.1	24.9	6.1	24.7	1.9	5.91
	71-99	58.3	21.6	20.1	41.0	0.0	5.58
	250-268	73.8	19.7	6.5	34.2	0.0	4.88
Sky Forest R.S.	0-15	71.2	18.5	10.3	0.0	2.2	5.53
	91-107	71.9	20.7	7.4	6.4	2.0	5.80
	208-231	76.2	18.1	5.7	5.2	0.3	5.50
Breezy Point	0-29	69.9	20.6	9.5	20.6	0.8	5.92
	102-127	73.0	19.2	7.8	25.5	0.0	5.68
	208-231	82.2	12.6	5.1	27.9	0.0	5.65
Camp O-Ongo	0-24	67.0	24.8	8.2	30.0	0.5	5.94
	72-93	65.0	22.2	12.9	50.0	4.4	5.63
	110-128	55.5	28.4	16.1	55.2	0.5	5.35
	128-149	56.9	35.0	8.2	93.4	0.0	5.36

Appendix C. PARTICLE SIZE DISTRIBUTION AND pH OF REPRESENTATIVE SOIL
SAMPLES FROM MAJOR STUDY PLOTS. (Continued)

Plot-site	Depths	Sand 2-.05 mm (%)	Silt .05-.002 mm (%)	Clay <.002 mm (%)	Fine Gravel 2-12mm (%)	Gravel >12mm (%)	pH
Green Valley Creek	0-29 98-121 212-234	76.6 78.7 84.2	16.1 17.2 13.0	7.3 4.1 2.8	48.8 52.8 28.6	1.9 0.6 0.1	6.05 5.78 5.21
NE Green Valley	0-22 81-104	82.4 84.7	11.5 12.6	6.1 2.8	37.6 31.4	0.8 0.0	6.00 6.13
Snow Valley	0-14 33-46	75.3 74.4	16.1 16.1	8.6 9.5	28.1 40.0	0.0 0.0	5.40 5.00
Bluff Lake	0-28 103-127 189-211	79.4 78.2 82.2	14.0 15.2 11.2	6.6 6.6 6.6	34.8 44.4 47.0	0.2 0.7 0.0	5.74 5.79 5.89
Holcomb Valley	0-13 28-43 94-110	69.4 67.3 70.7	18.8 16.2 14.8	11.8 16.5 14.5	30.0 71.0 83.1	3.7 0.3 2.3	6.18 6.43 7.70
Sand Canyon	0-25 87-110	79.9 82.0	12.6 14.9	7.5 3.2	39.6 34.1	0.1 0.0	6.52 6.08
Schneider Creek	0-14 81-104 166-189	79.8 81.7 81.4	14.1 12.9 13.1	6.1 5.3 5.6	104.2 63.1 58.2	0.9 0.1 0.0	6.51 6.45 6.46
Barton Flat	0-15 61-76	71.2 69.5	19.4 22.4	9.4 8.1	4.2 7.4	ND ND	6.15 6.45
Heart Bar	0-15 91-107 122-137	84.8 81.8 81.4	9.9 8.1 8.9	5.3 10.1 9.1	5.2 7.3 5.6	ND ND ND	6.81 6.11 6.13
Camp Osceola	0-15 61-76 91-107	17.9 67.6 67.5	21.7 21.0 18.2	10.4 11.4 14.3	5.2 7.4 10.1	ND ND ND	5.93 5.98 5.78

Appendix D. BULK DENSITY (D_b) OF SOILS OF MAJOR STUDY PLOTS

Plot	Site	Surface		Subsoil		Substratum	
		Depth (cm)	D_b (gm/cc)	Depth (cm)	D_b (gm/cc)	Depth (cm)	D_b (gm/cc)
DW	1	0-46	1.09	41-157	1.46	--	--
DW	2	0-43	1.13	43-147	1.64	147-267	1.57
DW	3	0-51	1.13	51-157	1.94	--	--
NE	13	0-50	1.07	50-189	1.61	189-272	1.53
S	22	0-20	1.20	20-145	1.53	145-290	1.70
SF		0-61	1.05	61-160	1.53	160-277	1.47
UCC		0-25	1.40	25-152	1.69	152-250	1.68
CP		0-27	1.12	27-80	1.65	--	--
BP		0-29	0.74	29-147	1.17	147-284	1.57
TUNE		0-28	1.18	28-90	1.67	--	--
COO		0-51	1.15	51-149	1.58	--	--
GVC		0-29	1.11	29-156	1.85	150-246	2.10
NEGV		0-22	1.31	22-150	2.15	--	--
SV		0-14	1.24	14-55	1.56	--	--
HV		0-13	1.46	13-117	1.77	--	--
BL		0-55	1.15	55-147	1.67	147-255	1.74
SC	1	0-25	1.30	25-110	1.80	--	--
SCR		0-20	1.19	20-145	1.75	145-234	1.73

Appendix E. EXCHANGEABLE AND SOLUBLE CATIONS OF SURFACE SOILS

Plot	Site	Depths (cm)	Exchangeable Cations				Soluble Cations			
			Ca	Mg (Meg/100g)	K	Na	Ca (Meg/100b)	Mg	K	Na
DW	1	0-24	3.64	0.72	0.499	0.032	0.028	0.011	0.018	0.012
DW	2	0-19	5.46	1.30	1.970	0.055	0.018	0.008	0.049	0.006
DW	3	0-25	2.92	0.59	0.482	0.030	0.020	0.010	0.019	0.013
NE	13	0-24	5.25	0.79	0.655	0.020	0.023	0.010	0.019	0.008
S	22	0-20	6.72	1.08	0.613	0.099	0.024	0.008	0.017	0.010
SF		0-15	7.31	1.39	0.493	0.006	0.073	6.029	0.020	0.014
UCC		0-25	4.87	1.23	0.566	0.081	0.023	0.010	0.015	0.009
CP		0-27	8.18	3.01	1.240	0.088	0.053	0.034	0.038	0.012
BP		0-29	10.44	2.78	0.914	0.052	0.060	0.031	0.027	0.012
TUNE		0-28	5.33	1.04	0.767	0.026	0.041	0.016	0.051	0.021
COO		0-24	10.47	2.06	1.140	0.076	0.057	0.019	0.039	0.006
GVC		0-29	3.75	0.79	0.352	0.018	0.016	0.004	0.010	0.007
NEGV		0-22	5.28	0.84	0.370	0.045	0.030	0.010	0.010	0.007
SV		0-14	6.17	1.65	0.261	0.008	0.014	0.005	0.011	0.006
HV		0-13	9.41	2.13	0.486	0.014	0.038	0.011	0.011	0.006
BL		0-28	3.32	0.44	0.266	0.028	0.034	0.015	0.011	0.006
SC	1	0-25	4.35	2.93	0.134	0.052	0.021	0.008	0.005	0.012
SC	2	0-24	13.55	2.24	0.227	0.012	0.148	0.041	0.012	0.009
SCR		0-14	9.92	1.32	0.610	0.014	0.277	0.046	0.070	0.016
BF		0-15	11.05	1.45	0.770	0.023	0.072	0.028	0.033	0.016
CAO		0-15	4.27	0.96	0.393	0.043	0.031	0.013	0.020	0.006
HB		0-15	5.00	0.88	0.520	0.015	0.024	0.009	0.015	0.008

Appendix F. EXCHANGEABLE AND SOLUBLE CATIONS OF REPRESENTATIVE SUBSOIL LAYERS

Plot	Site	Depths (cm)	Exchangeable Cations				Soluble Cations			
			Ca	Mg	K	Na (meq/100 gm)	Ca	Mg	K	Na
DW	1	77-99	2.83	1.53	0.347	0.056	0.008	0.005	0.004	0.014
DW	2	67-91	2.93	1.14	0.609	0.068	0.005	0.003	0.011	0.006
DW	3	89-111	0.71	0.36	0.317	0.040	0.004	0.003	0.007	0.014
NE 13		84-109	1.79	0.52	0.529	0.033	0.007	0.003	0.008	0.007
S 22		79-99	3.47	1.54	0.340	0.084	0.008	0.004	0.008	0.009
SF		76-91	4.48	1.63	0.432	0.023	0.016	0.008	0.007	0.011
UCC		71-99	7.45	2.12	0.609	0.108	0.003	0.001	0.004	0.006
UCC		216-250	16.30	4.29	0.068	0.305	0.003	0.001	0.001	0.015
CP		64-80	6.09	2.48	1.250	0.021	0.015	0.009	0.020	0.006
BP		80-102	7.68	2.52	0.860	0.059	0.014	0.007	0.012	0.011
BP		231-264	14.35	2.97	0.134	0.215	0.006	0.002	0.001	0.019
TUN2		79-90	3.08	0.92	0.515	0.018	0.014	0.006	0.014	0.008
COO		93-110	12.89	2.66	0.155	0.121	0.011	0.003	0.002	0.009
GVC		137-156	7.38	1.27	0.045	0.180	0.003	0.001	0.001	0.013
NEGV		81-104	6.64	0.46	0.072	0.070	0.018	0.002	0.002	0.010
SV		46-55	5.57	1.01	0.142	0.006	0.009	0.002	0.006	0.009
HV		62-80	23.55	2.14	0.256	0.017	0.095	0.018	0.006	0.010
BL		103-127	1.21	0.20	0.084	0.048	0.005	0.001	0.001	0.012
SC	1	89-110	13.60	4.01	0.049	0.085	0.007	0.002	0.002	0.012
SC	2	89-112	8.12	1.52	0.119	0.025	0.077	0.028	0.005	0.007
SCR		81-104	2.59	0.40	0.505	0.011	0.016	0.004	0.016	0.008
BF		61-76	5.68	0.79	0.602	0.030	0.024	0.007	0.011	0.009
CAO		76-91	3.10	1.00	0.418	0.036	0.007	0.004	0.006	0.008
HB		91-107	3.17	0.90	0.227	0.026	0.008	0.005	0.006	0.012

Appendix G. ORGANIC CARBON (C) AND NITROGEN (N) IN THE SURFACE SOILS
TO A DEPTH OF 25 cm.

Plot	Site	C (g/100g)	N (g/100g)	C/N
Dogwood	1	2.56	0.094	27.3
Dogwood	2	1.88	0.069	27.2
Dogwood	3	3.46	0.105	33.0
NE 13		2.70	0.097	27.9
S 22		1.70	0.071	23.9
Sky Forest R.S.		2.03	0.076	26.8
U.C. Conference Center		1.10	0.040	27.5
Camp Paivika		1.78	0.081	22.0
Breezy Point		2.08	0.102	20.4
Tunnel-2		1.63	0.051	32.0
Camp O-Ongo		1.72	0.122	14.1
Green Valley Creek		0.93	0.036	25.8
N.E. Green Valley		1.47	0.061	24.1
Snow Valley		0.83	0.041	20.4
Holcomb Valley		1.14	0.054	21.1
Bluff Lake		3.42	0.118	29.0
Sand Canyon	1	0.65	0.031	21.0
Sand Canyon	2	1.78	0.084	21.1
Schneider Creek		2.15	0.092	23.5
Barton Flat		2.99	0.119	25.1
Camp Osceola		1.14	0.043	26.8
Heart Bar		0.87	0.034	25.6

Appendix H. AVAILABLE SOIL WATER STORAGE CAPACITY OF MAJOR STUDY PLOTS

Plot-Site	Soil Depth	<u>Available Water</u>		Soil Depth	Total Available Water
	(cm)	(Vol.%)	(cm)	(cm)	(cm)
Breezy Point	152	15.4	23.4	256	39.2
Sky Forest	152	14.3	21.8	208	30.6
Green Valley Creek	152	14.3	21.7	203	28.9
Bluff Lake	152	13.9	21.2	223	28.4
Dogwood-2	152	13.5	20.6	267	29.0
Dogwood-1	152	13.4	20.4	Not sampled	
NE 13	152	12.9	19.6	272	37.4
U.C. Conf. Cen.	152	12.4	18.9	269	27.9
Dogwood-3	152	12.2	18.5	Not sampled	
S 22	152	10.6	16.1	208	18.4
Schneider Creek	152	8.9	13.5	221	28.8
Camp O-Ongo	152	8.6	13.1	152	13.1
Sand Canyon	152	7.7	11.7	262	13.8
Tunnel-2		12.5		86	10.8
NE Green Valley		10.3		121	12.4
Camp Paivika		8.1		80	6.5
Holcomb Valley		8.4		116	9.7
Snow Valley		16.3		61	9.9
Range		7.7-15.4	11.7-23.4		6.5-39.2
Mean		11.9	18.5		21.6

Appendix I. VEGETATION ZONES, VEGETATION TYPES, AND MAJOR SPECIES IN THE SAN BERNARDINO MOUNTAINS.

Vegetation zone ^a	Horton's vegetation type ^a	Minnich's vegetation type ^b	Major species
Chamise-Chaparral	Pure chamise-chaparral	None	<u>Adenostoma fasciculatum</u>
	Chamise-ceanothus chaparral	Soft chaparral	<u>Adenostoma fasciculatum</u> , <u>Ceanothus crassifolius</u> , <u>C. leucodermis</u> , <u>Quercus dumosa</u> , <u>Photinia arbutifolia</u> , <u>Rhus ovata</u>
	Chamise-manzanita	Hard chaparral	<u>Adenostoma fasciculatum</u> , <u>Arctostaphylos glauca</u> , <u>A. glandulosa</u> , <u>Ceanothus crassifolius</u> , <u>C. leucodermis</u>
	Scrub oak chaparral	Oak chaparral	<u>Quercus dumosa</u> , <u>Q. wislizenii</u> , <u>Cercocarpus betuloides</u> , <u>Ceanothus leucodermis</u> , <u>Garrya veatchii</u> , <u>Arctostaphylos glandulosa</u>
	Coastal sagebrush	Coastal sage scrub	<u>Artemisia californica</u> , <u>Salvia apiana</u> , <u>Eriogonum fasciculatum</u> , <u>Encelia farinosa</u> , <u>Salvia mellifera</u> , <u>Deplacus longiflorus</u>
Woodland-Chaparral	Live oak chaparral	Emergent oak woodland	<u>Quercus wislizenii</u> , <u>Q. chrysolepis</u> plus hard chaparral species
	Live oak woodland	Interior oak woodland	<u>Quercus wislizenii</u> , <u>Q. chrysolepis</u> , <u>Pseudotsuga macrocarpa</u> , <u>Cercocarpus ledifolius</u>

Appendix I. VEGETATION ZONES, VEGETATION TYPES, AND MAJOR SPECIES IN THE SAN BERNARDINO MOUNTAINS.
(Continued)

Vegetation zone ^a	Horton's vegetation type ^a	Minnich's vegetation type ^b	Major species
Pinyon-Juniper Woodland	Big-cone Douglas fir forest	Big-cone Douglas fir forest	<u>Pseudotsuga macrocarpa</u> , <u>Quercus chrysolepis</u>
	Great Basin sagebrush	Great Basin sagebrush	<u>Artemisia tridentata</u> , <u>Artemisia arbuscula nova</u> , <u>Chrysothamnus nauseosus</u> , <u>Coleogyne ramossiasima</u> , <u>Eriogonum spp.</u> , <u>Salvia spp.</u>
	none	Joshua Tree woodland	<u>Yucca occidentalis</u> , <u>Yucca brevifolia</u> , <u>Chrysothamnus nauseosus</u>
Timberland Chaparral	none	Juniper-Joshua Tree woodland	<u>Juniperus occidentalis</u> , <u>Yucca brevifolia</u> , <u>Artemisia tridentata</u> , <u>Chrysothamnus nauseosus</u>
	Timberland chaparral	Timberland chaparral	<u>Arctostaphylos patula</u> , <u>Ceanothus cordulatus</u> , <u>Castanopsis sempervirens</u>
Coniferous Forest	Pine forest	none (see Coulter pine forest, dry forest)	<u>Pinus ponderosa</u> , <u>Pinus jeffreyi</u> , <u>Pinus coulteri</u> , <u>Quercus kelloggii</u>
	Ponderosa pine-white fir forest	Mixed yellow pine-white fir forest	<u>Pinus ponderosa</u> , <u>Pinus jeffreyi</u> , <u>Abies concolor</u> , <u>Pinus lambertiana</u> , <u>Libocedrus decurrens</u> , <u>Quercus kelloggii</u>

Appendix I. VEGETATION ZONES, VEGETATION TYPES, AND MAJOR SPECIES IN THE SAN BERNARDINO MOUNTAINS.
(Continued)

Vegetation zone ^a	Horton's vegetation type ^a	Minnich's vegetation type ^b	Major species
Coniferous Forest	Sugar pine-white fir forest	none (see pure yellow pine-white fir forest)	<u>Pinus lambertiana</u> , <u>P. jeffreyi</u> , <u>Abies concolor</u> , <u>Quercus chrysolepis</u> , plus timberland chaparral species
	Grassland	Grassland or meadow	<u>Bromus spp.</u> , <u>Carex spp.</u> , <u>Juncus spp.</u>
	Black oak woodland	none (see dry forest)	<u>Quercus kelloggii</u> , <u>Quercus chrysolepis</u> , <u>Pinus ponderosa</u> , <u>Pseudotsuga macrocarpa</u> , <u>Ceanothus integrifolius</u>
	Alpine forest	Subalpine forest	<u>Pinus contorta</u> , <u>P. flexilis</u> , plus timberland chaparral species
	Barren areas	Krummholz	<u>Pinus contorta</u> , <u>Pinus flexilis</u> , plus stunted timberland chaparral species
	none	Barren	none
	none	Marginal conifer forest	A mixture between pure yellow pine-white fir forest and timberland chaparral species
	none (see Pine forest, ponderosa pine-white fir forest)	Pure yellow pine-white fir forest	<u>Pinus ponderosa</u> , <u>P. jeffreyi</u> , <u>P. lambertiana</u> , <u>Libocedrus decurrens</u> , <u>Abies concolor</u>

Appendix I. VEGETATION ZONES, VEGETATION TYPES, AND MAJOR SPECIES IN THE SAN BERNARDINO MOUNTAINS.
(Continued)

Vegetation zone	Horton's vegetation type	Minnich's vegetation type	Major species
All zones	none (see Pine forest, black oak woodland)	Dry forest	<u>Pinus coulteri</u> , <u>Quercus kelloggii</u>
	none	Riverine vegetation	<u>Platanus racemosa</u> (below 4,000 ft), <u>Populus trichocarpa</u> (below 4,000 ft), <u>Alnus rhamnifolia</u> (4,000-7,000 ft), <u>Salix</u> spp. (above 7,000 ft), <u>Populus tremuloides</u> (Fish Creek)
Woodland- Chaparral	Knobcone pine forest	Knobcone pine forest	<u>Pinus attenuata</u> , <u>Adenostoma fasciculatum</u> , <u>Arctostaphylos glandulosa</u> , <u>Ceanothus leucodermis</u> , <u>Pickeringia montana</u>
	none (see pine forest)	Coulter pine forest	<u>Pinus coulteri</u> , <u>Quercus wislizenii</u> , <u>Q. chrysolepis</u> , plus hard chaparral species
Desert Chaparral	Desert chaparral	Desert chaparral	<u>Cercocarpus ledifolius</u> , <u>Quercus wislizenii</u> , <u>Q. dumosa</u> , <u>Q. chrysolepis</u> , <u>Ceanothus greggii</u> , <u>C. crassifolius</u> , <u>Fremontia californicus</u> , <u>Garrya veatchii</u>
Pinyon- Juniper Woodland	Pinyon-Juniper woodland	Western Juniper- mountain mahogany woodland	<u>Juniperus occidentalis</u> , <u>Cercocarpus ledifolius</u> , <u>Artemisia tridentata</u> , <u>Chrysothamnus nauseosus</u>

Appendix I. VEGETATION ZONES, VEGETATION TYPES, AND MAJOR SPECIES IN THE SAN BERNARDINO MOUNTAINS.
(Continued)

Vegetation zone ^a	Horton's vegetation type ^a	Minnich's vegetation type ^b	Major species
		Pinyon pine woodland	<u>Pinus monophylla</u> , <u>P. quadrifolia</u> , <u>Juniperus californica</u> , <u>J.</u> <u>occidentalis</u> , <u>Cercocarpus ledi-</u> <u>folius</u> , <u>Artemisia tridentata</u> , <u>Chrysothamnus nauseosus</u>
		Pinyon-Juniper woodland	<u>Pinus monophylla</u> , <u>P. quadrifolia</u> , <u>Juniperus californica</u> , <u>J.</u> <u>occidentalis</u> , <u>Cercocarpus ledi-</u> <u>folius</u> , <u>Artemisia tridentata</u> , <u>Chrysothamnus nauseosus</u> , <u>Arctostaphylos glauca</u> , <u>Quercus</u> <u>dumosa</u>
All Zones	none	Subclimax vegetation	Varies with site
Outside of Above Zone	none	Open desert vegetation	

^a Horton (1960)

^b Minnich and others (1969)

Appendix J. PRELIMINARY ANALYSIS OF NUMBER OF ATTACKS AND GALLERY LENGTH FOR THE MOUNTAIN PINE BEETLE FROM VARYING BARK SAMPLE SIZES (DATA CONVERTED TO 1000 cm² FOR COMPARISON), EPA, SAN BERNARDINO AIR POLLUTANT STUDY, 1974.

Location of Sample	Sample Size (cm ²)	Number of Attacks			Gallery Length		
		Number of samples	Mean	Standard Deviation	Number of samples	Mean (cm)	Standard Deviation (cm)
Base of Infestation	100	10	3.00	6.75	10	246.0	182.9
	100	10	4.00	9.66	10	278.0	198.3
	250	10	3.60	3.98	10	243.6	155.9
	500	10	3.00	3.43	10	230.8	123.5
	1000	10	3.00	2.71	10	195.5	95.1
Middle of Infestation	100	9	5.56	5.27	10	230.0	114.8
	100	9	5.56	5.27	10	266.0	130.8
	250	9	4.00	3.46	10	253.2	120.4
	500	9	2.89	1.76	10	243.8	87.0
	1000	8	3.00	2.45	9	216.8	78.2
Top of Infestation	100	10	0	0	10	142.0	99.4
	100	10	0	0	10	160.0	113.2
	250	10	0	0	10	141.6	80.8
	500	8	1.00	1.51	8	159.8	93.9
	1000	6	1.50	1.97	5	147.8	129.3

Appendix K. PRELIMINARY ANALYSIS OF NUMBER OF ATTACKS AND GALLERY LENGTH FOR THE JEFFREY PINE BEETLE FROM VARYING BARK SAMPLE SIZES (DATA CONVERTED TO 1000 cm² FOR COMPARISON), EPA, SAN BERNARDINO AIR POLLUTANT STUDY, 1974.

Location of Sample	Sample Size (cm ²)	Number of Attacks			Gallery Length		
		Number of samples	Mean	Standard Deviation	Number of samples	Mean (cm)	Standard Deviation (cm)
Base of Infestation	100	12	3.33	4.92	12	146.7	89.98
	100	12	3.33	4.92	12	156.7	96.42
	250	12	2.00	2.09	12	144.3	63.04
	500	12	3.33	2.31	12	144.5	56.90
	1000	12	2.83	1.58	12	136.7	52.81
Middle of Infestation	100	12	3.33	6.51	12	135.8	107.7
	100	12	3.33	6.51	12	141.7	112.4
	250	12	2.67	4.29	12	133.3	78.32
	500	12	2.83	3.01	12	117.7	67.30
	1000	12	2.91	2.57	12	112.8	57.05
Top of Infestation	100	12	2.50	4.52	12	71.67	59.52
	100	12	4.17	5.15	12	89.17	69.86
	250	12	2.33	3.17	12	82.00	62.93
	500	12	2.67	2.87	12	80.00	59.60
	1000	12	2.42	2.35	12	84.25	52.47

Appendix L. TOTAL ARTHROPODS REARED FROM MOUNTAIN PINE BEETLE INFESTED
PONDEROSA PINE BOLTS FROM THREE HEIGHTS IN 1974, SAN
BERNARDINO.

Arachnida			Colydiidae		
Araneae	3		<u>Lasconotus</u> sp	10	
Pseudoscorpionida			<u>Aulonium</u> sp	138	
Chernetidae	68		Othniidae		
Insecta			<u>Othnius</u> sp	28	
Hemiptera			Tenebrionidae		
Anthocoridae			<u>Corticeus</u> sp.	38	
<u>Lyctocoris</u> sp.	2		Melandryidae		
<u>Species #2</u>	1		<u>Rushia</u> sp.	127	
Unknown nymphs	8		Bostrichidae		
Neuroptera			<u>Species #1</u>	14	
Inocelliidae			Curculionidae		
<u>Inocellia</u> sp.	14		<u>Cossonus</u> sp.	293	
Raphidiidae			<u>Lechriops</u> sp.	1	
<u>Agulla</u> sp.	52		Scolytidae		
Chrysopidae			<u>Dendroctonus</u>		
<u>Species #1</u>	1		<u>valens</u> LeC.	1	
Unknown larvae	2		<u>D. brevicomis</u>	11	
Coleoptera			<u>Pityokteines</u> sp.	307	
Histeridae			<u>Gnathotrichus</u> sp.	32	
<u>Plegaderus</u> sp.	338		Unknown larvae		
<u>Platysoma</u> sp.	10		<u>Species #3</u>	256	
larva #1	18		Lepidoptera		
larva #2	2		Unknown species	2	
Scaphidiidae			Diptera		
<u>Species #1</u>	1		Ceratopogonidae		
Staphylinidae			<u>Species #1</u>	233	
<u>Nudobius</u> sp.	4		Sciaridae		
<u>Species #2</u>	1		<u>Species #1</u>	21	
Dermestidae			Scatopsidae		
<u>Species #1</u>	2		<u>Species #1</u>	1	
Ostomidae			Cecidomyiidae		
<u>Temnochila</u> sp.	119		<u>Species #1</u>	5	
<u>Tenebroides</u> sp.	4		Stratiomyidae		
Cleridae			<u>Zabrachia</u> sp.	289	
<u>Enoclerus</u> sp.	171		Scenopinidae		
<u>Species #4</u>	4		<u>Belosta</u> sp.	27	
Rhizophagidae			Empididae		
<u>Rhizophagus</u>	2		<u>Drapetis</u> sp.	11	
Cryptophagidae			Dolichopodidae		
<u>Salebis</u> sp.	3		<u>Medetera</u> sp.	7	
Nitidulidae			<u>Species #2</u>	2	
<u>Species #1</u>	1		Phoridae		
Lathridiidae			<u>Species #1</u>	51	
<u>Corticaria</u> sp.	12				

Appendix L. TOTAL ARTHROPODS REARED FROM MOUNTAIN PINE BEETLE INFESTED
PONDEROSA PINE BOLTS FROM THREE HEIGHTS IN 1974, SAN
BERNARDINO. (Continued)

Diptera (continued)

Londraeidae	
Species #1	33
Milichiidae	
Species #1	22
Drosophilidae	
Species #1	8
Sarcophagidae	
Species #1	2
Unknown larvae	
Species #1	116
Hymenoptera	
Braconidae	
Species #1	2
Species #2	1
Encyrtidae	
Species #1	8
Species #4	2
Species #6	1
Torymidae	
<u>Roptrocerus</u> sp.	81
Pteromalidae	
Species #1	5
Bethylidae	
Species #1	1
Formicidae	
Species #2	1
Sphecidae	
<u>Pemphredon</u> sp.	1

Appendix M. TOTAL ARTHROPODS REARED FROM JEFFREY PINE BEETLE INFESTED
JEFFREY PINE BOLTS FROM THREE HEIGHTS IN 1974, SAN
BERNARDINO

Arachnida			
Araneae	156	Tenebrionidae	
Pseudoscorpionida		Larvae #1	26
Chernetidae	31	Curculionidae	
Insecta		<u>Cossonus</u> sp.	1
Neuroptera		Scolytidae	
Inocelliidae		<u>Ips pini</u> Lanier	1
<u>Inocellia</u> sp.	3	<u>Ips latidens</u> (LeC)	2
Raphidiidae		<u>Pityokteines</u>	
<u>Agulla</u> sp.	2	<u>ornatus</u> (Swaine)	3
Coleoptera		<u>Gnathotrichus</u> sp	189
Scaphidiidae		Unknown Larvae #1	1
Species #1	1	Lepidoptera	
Staphylinidae		Larva #1	1
Species #1	1	Species #2	1
#2	1	Diptera	
#4	1	Ceratopogonidae	
larvae	25	Species #1	2,993
Clambidae		Mycetophilidae	
1 species	1	Species #1	1
Dermestidae		Sciaridae	
Megatoma sp.	1	Species #1	40
larvae #1	13	Scatopsidae	
Malachiidae		Species #1	1
Species #1	1	Cecidomyiidae	7
Ostomidae		Stratiomyidae	
<u>Temnochila</u> sp.	44	<u>Zabrachia</u> sp.	28
Cleridae		Scenopinidae	
<u>Enoclerus</u> sp.	57	<u>Belosta</u> sp.	2
Species #3	15	Empididae	
Buprestidae		<u>Drapetis</u> sp.	9
Larvae #1	12	Dolichopodidae	
Rhizophagidae		<u>Medetera</u> sp.	7
<u>Rhizophagus</u> sp.	1	Species #2	1
Cryptophagidae		Phoridae	
<u>Salebius</u> sp.	8	Species #1	224
Nitidulidae		Milichiidae	
Species #1	2	Species #1	23
Colydiidae		Unknown larvae	
<u>Lasconotus</u> sp.	3	Species #1	91
<u>Aulonium</u> sp.	1	Species #2	28
Othniidae		Species #4	27
<u>Othnius</u> sp.	21		

Appendix M. TOTAL ARTHROPODS REARED FROM JEFFREY PINE BEETLE INFESTED
JEFFREY PINE BOLTS FROM THREE HEIGHTS IN 1974, SAN
BERNARDINO (Continued)

Hymenoptera	
Braconidae	
Species #1	12
Encyrtidae	
Species #1	10
#2	1
#3	10
#4	2
#5	1
<u>Avetienella</u> sp.	3
Eurytomidae	
<u>Eurytoma</u> sp.	2
Diapriidae	
Species #1	1
Formicidae	
Species #1	24
Colletidae	
Species #1	1

Appendix N. TAXONOMIC LIST OF SOIL MICROARTHROPODS COLLECTED FROM THE
BREEZY POINT, SNOW VALLEY AND NEGV STUDY PLOTS, 1973-74.

Insecta

Protura

Campodeidae

Japygidae

Lepismatidae

Collembola

Istomidae

Entomobryidae

Poduridae

Onychiuridae

Sminthuridae

Thysanoptera

Pscocoptera

Hymenoptera

Diptera

Coleoptera

Staphylinidae

Silphidae

Curculionidae

Lathridiidae

Raphidiidae

Myriapoda

Diplopoda

Chilopoda

Geophilidae

Scutigermorpha

Symphyla

Pauropoda

Arachnida

Araneida

Chelonethida

Acarina

Prostigmata

Labidostomidae

Eupodidae

Bdellidae

Nanorchestidae

Stigmaeidae

Cunaxidae

Ragidiidae

Erythraeidae

Anystidae

Neophylobiidae

Appendix N. TAXONOMIC LIST OF SOIL MICROARTHROPODS COLLECTED FROM THE
BREEZY POINT, SNOW VALLEY, AND NEGV STUDY PLOTS, 1973-74
(Continued)

Arachnida (continued)	<u>Gymnodamaeus</u> sp.
Tydeidae	
Cryptognathidae	Damaeidae ^b
Raphignathidae	Genus 1 sp. 3
Cheyletidae	Genus 1 sp. 6
Linotetranaidae	Genus 2 sp. 5
Paratydeidae	Genus 5 sp. 3
Trombidiidae	Eremaeidae
Caeculidae	<u>Eremaeus stiktos</u> Higgins
Mesostigmata	<u>Eremaeus</u> sp. (two species)
Zerconidae	Oribatulidae
Trachytidae	<u>Scheloribates</u> sp.
Phytoseidae	<u>Hemileius</u> sp.
Ascidae	Liacaridae
Hypoaspidae	<u>Liacarus</u> sp. nr.
Pachylaelaptidae	Charassobatidae
Rhodacaridae	<u>Ametroproctus</u> sp.
Cryptostigmata ^a	
Gymnodamaeidae	Cepheidae
<u>Jacotella</u> sp.	<u>Eupterotegaeus</u> sp.

^a Cryptostigmatid identifications by R. A. Norton, State Univ. of
New York, Syracuse Campus

^b Genus and species numbers refer to Norton terminology.

Appendix N. TAXONOMID LIST OF SOIL MICROARTHROPODS COLLECTED FROM THE
BREEZY POINT, SNOW VALLEY, AND NEGV STUDY PLOTS, 1973-74
(Continued)

Passalozetidae

Passalozetes sp.

Hermanniellidae

Hermanniella sp.

Palaeacaridae

Palaeacarus sp.

Cosmochthonoidea

Cosmochthonius sp.

Aphelacaridae

Aphelacarus sp.

Camisiidae

Camisia sp.

Ceratozetidae

Propelops sp.

Galumnidae

Philogalumna sp.

Tectocepheidae

Tectocepheus sarekensis Tragardh

Appendix O. THE NUMBER OF CONES PRODUCED BY JEFFREY AND PONDEROSA PINES OF DIFFERENT CROWN CLASSES DURING 1973 AND 1974.

Part A. Ponderosa pine.

Plot name	Year	Dom.	Co-Dom.	Crown classes			Total Cones
				Inter.	Inter. Open	Inter. Suppr.	
				Number of Cones/Number of Trees			
CP	1973	137/37(7) ^a	0/24	0/5	0/10	0/0	137
	1974	275/37(19)	26/24(5)	0/5	0/10	0/0	301
BP	1973	1/25(1)	0/24	0/8	0/9	0/6	1
	1974	165/25(10)	90/24(6)	0/8	0/9	0/5	255
DWA	1973	0/6	0/8	0/3	0/4	0/0	0
	1974	609/16(9)	79/19(5)	0/25	1/11(1)	0/0	689
TUN 2	1973	1624/25(14)	144/20(6)	0/7	0/7	0/12	1768
	1974	1698/25(20)	432/20(10)	0/7	0/7	0/12	2120
SF	1973	98/31(16)	14/22(5)	0/23	1/16(1)	0/21	113
	1974	2022/31(24)	582/22(13)	35/23(2)	8/16(1)	0/20	2648
UCC	1973	11/16(4)	1/25(1)	0/11	0/9	0/4	12
	1974	300/15(9)	175/25(8)	0/11	8/9(1)	0/4	483
COO	1973	9/29(3)	0/16	0/2	0/5	0/5	9
	1974	382/29(2)	18/16(1)	0/3	0/5	0/5	400
CA	1973	1395/9(9)	388/17(3)	0/5	8/4(1)	0/0	1706
	1974	1317/12(13)	1276/17(19)	28/12(3)	86/5(2)	0/0	2701

Appendix O. THE NUMBER OF CONES PRODUCED BY JEFFREY AND PONDEROSA PINES OF DIFFERENT CROWN CLASSES DURING 1973 AND 1974 (Continued)

<u>Plot name</u>	<u>Year</u>	<u>Dom.</u>	<u>Co-Dom.</u>	<u>Inter.</u>	<u>Inter. Open</u>	<u>Inter. Suppr.</u>	<u>Suppr.</u>	<u>Total Cones</u>
SCR	1973			N O D A T A T A K E N				
	1974	5735/31(30)	402/17(2)	63/1(1)	0/0	0/0	0/0	6208
BF	1973	0/10	8/8(1)	0/3	0/4	0/0	0/0	8
	1974	534/11(8)	327/4(3)	0/4	0/4	0/1	0/0	361

Part B. Jeffrey Pine.

GVC	1973	452/35(24)	0/12	0/9	0/5	0/0	0/4	452
	1974	3903/35(28)	0/12	26/9(1)	0/5	0/0	0/4	3929
SV	1973	37/24(7)	45/23(6)	0/3	2/9(1)	0/0	0/9	84
	1974	119/28(11)	87/25(5)	0/13	0/27	0/0	0/9	206
NEGV	1973	100/20(18)	113/15(7)	7/18(2)	0/6	0/5	0/1	220
	1974	600/20(13)	189/15(16)	16/18(3)	5/6(2)	1/5(1)	0/1	811
BL	1973	170/22(19)	33/23(4)	2/32(1)	3/31(2)	0/14	0/13	208
	1974	119/22(11)	79/23(8)	0/32	0/31	0/14	0/13	198
HV	1973			N O D A T A T A K E N				
	1974	199/34(21)	58/37(14)	4/48(2)	0/29	0/0	0/18	261
SC	1973	219/21(14)	137/12(6)	0/1	1/6(1)	0/0	0/0	357
	1974	62/21(9)	1/12(7)	7/5(3)	0/9	0/0	0/6	70
HB	1973	27/43(6)	2/28(1)	0/1	0/26	0/7	0/5	19
	1974	321/44(19)	18/28(5)	0/1	0/29	1/7(1)	0/5	340

Appendix O. THE NUMBER OF CONES PRODUCED BY JEFFREY AND PONDEROSA PINES OF DIFFERENT CROWN CLASSES DURING 1973 AND 1974 (Continued)

<u>Plot name</u>	<u>Year</u>	<u>Dom.</u>	<u>Co-Dom.</u>	<u>Inter.</u>	<u>Inter.</u> <u>Open</u>	<u>Inter.</u> <u>Suppr.</u>	<u>Suppr.</u>	<u>Total</u> <u>Cones</u>
CAO	1973							
	1974	1238/16(10)	163/30(8)	NO DATA TAKEN 138/34(4)	0/11	0/1	0/29	1541
BF	1973	0/4	0/0	0/0	0/0	0/0	0/0	0
	1974	50/23(4)	185/44(9)	5/68(1)	0/11	0/0	0/50	240
SCR	1973							
	1974	109/3(2)	0/0	NO DATA TAKEN C	0/1	0/0	0/1	109

^a Number in parenthesis is number of trees in that crown class which produced cones.